NEW

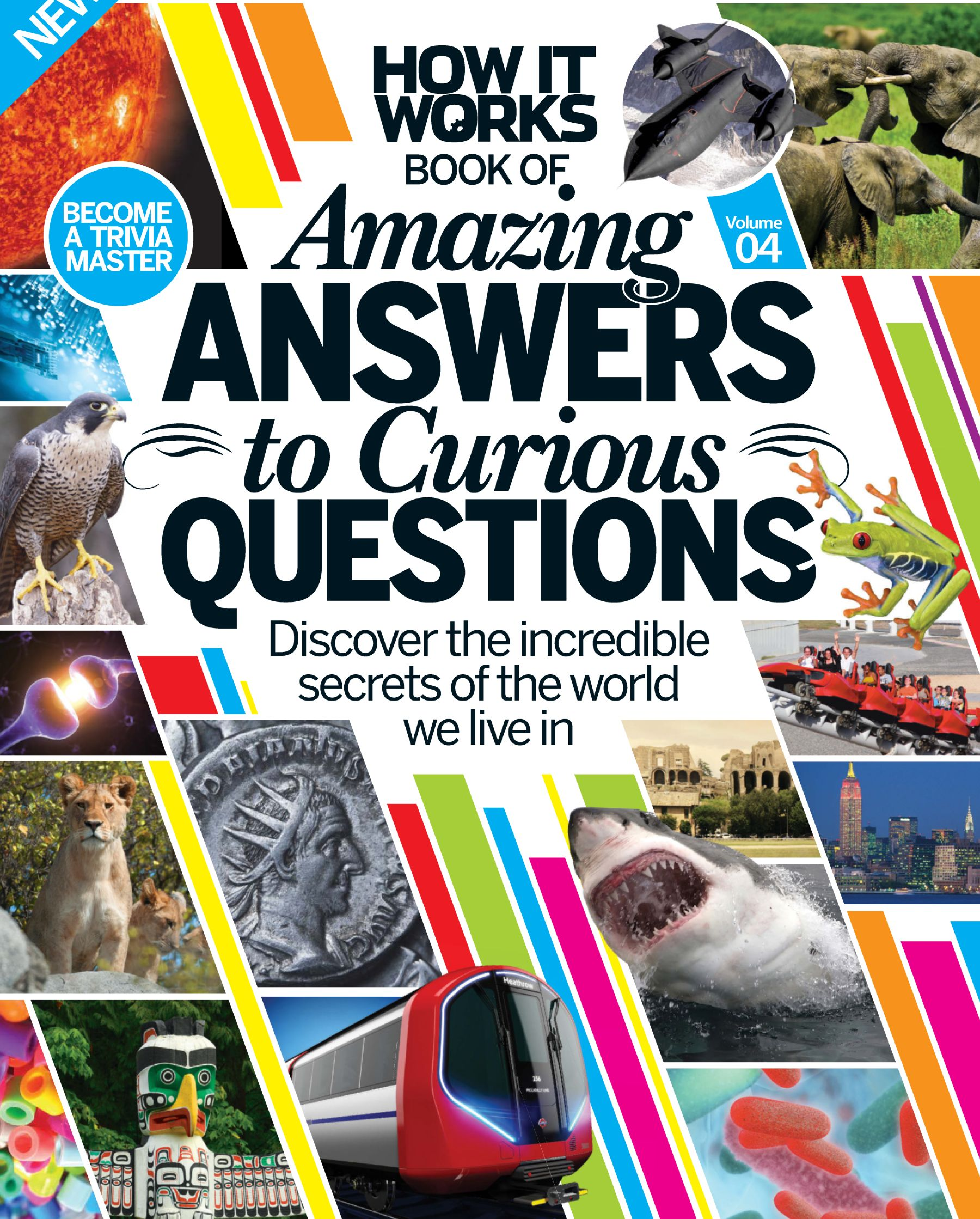
TECHNOLOGY TRANSPORT SCIENCE SPACE ENVIRONMENT HISTORY

HOW IT WORKS BOOK OF
Amazing ANSWERS *to Curious* QUESTIONS

Volume 04

BECOME A TRIVIA MASTER

Discover the incredible secrets of the world we live in



Welcome to

Amazing ANSWERS to Curious QUESTIONS

If you're curious about the world we live in, then you've come to the right place. The How It Works Book of Amazing Answers to Curious Questions Volume 4 Revised Edition is packed full of features to satisfy even the most inquiring of minds. Would you like to know exactly how cloud storage works? Turn to the Technology section. Are you interested in finding out how the cars and tubes of the future will drive themselves? Check out the Transport section. We've also got questions and answers on Science, Space, the Environment and History, so if you've ever wondered how Ebola can spread so quickly, whether there are Alien Earths that allow human life, why animals migrate vast distances or what life was like inside a Whippet tank in World War I, read on to discover the amazing answers!

HOW IT WORKS BOOK OF *Amazing* ANSWERS *to Curious* QUESTIONS

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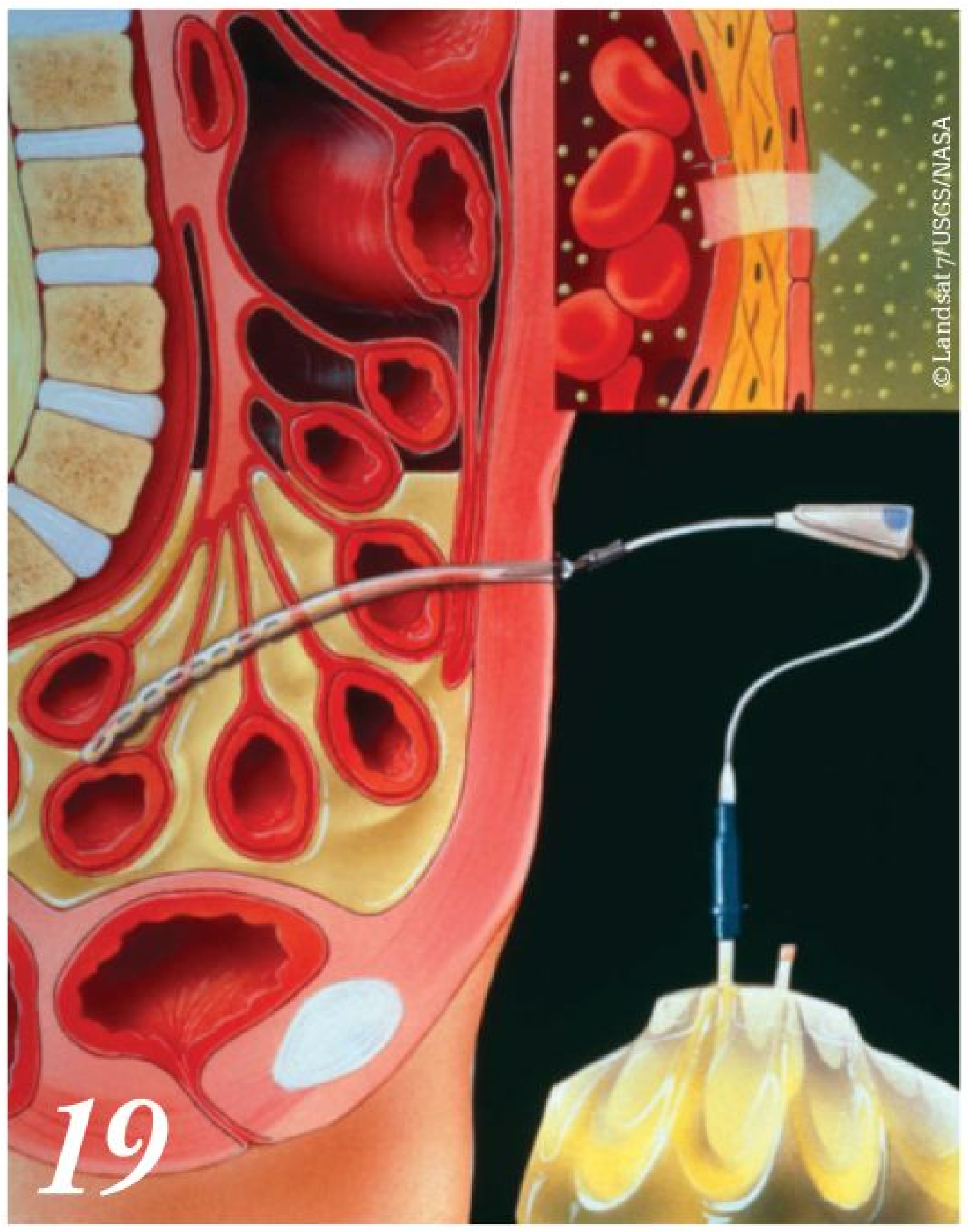
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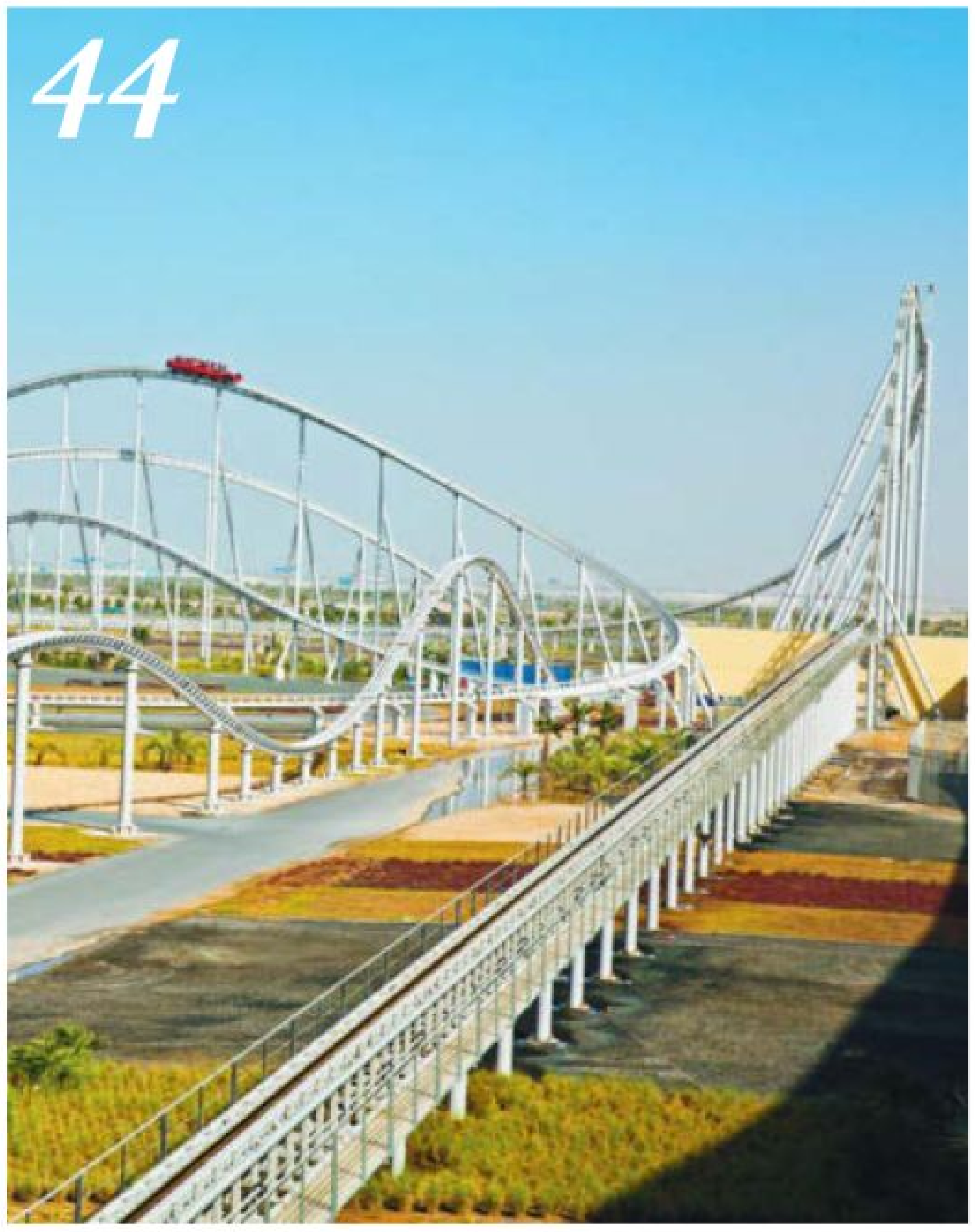

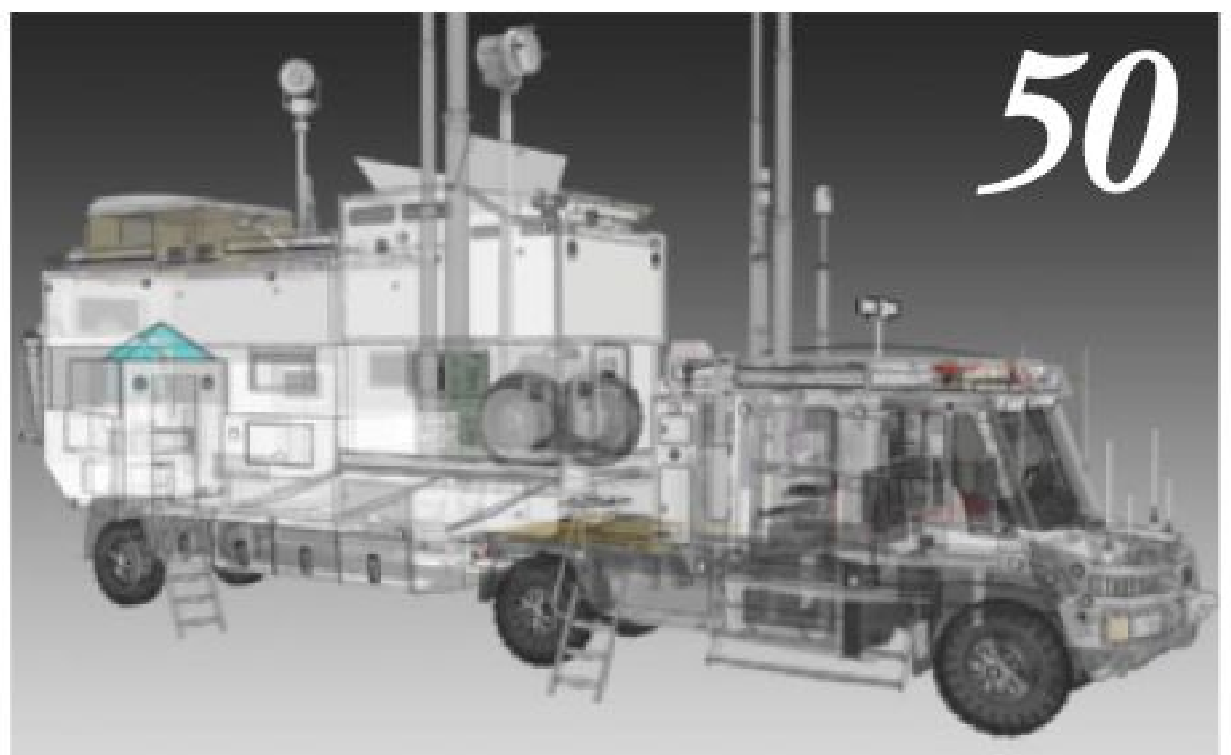

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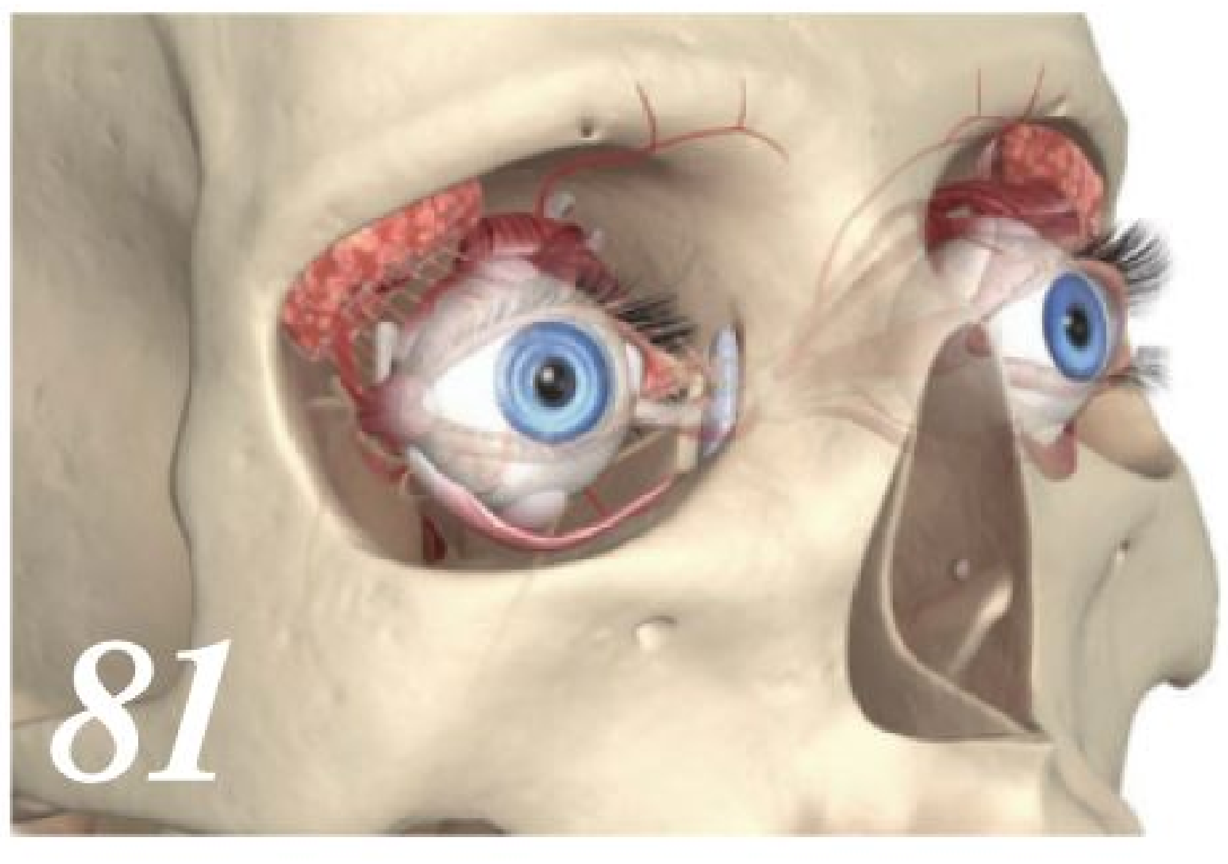

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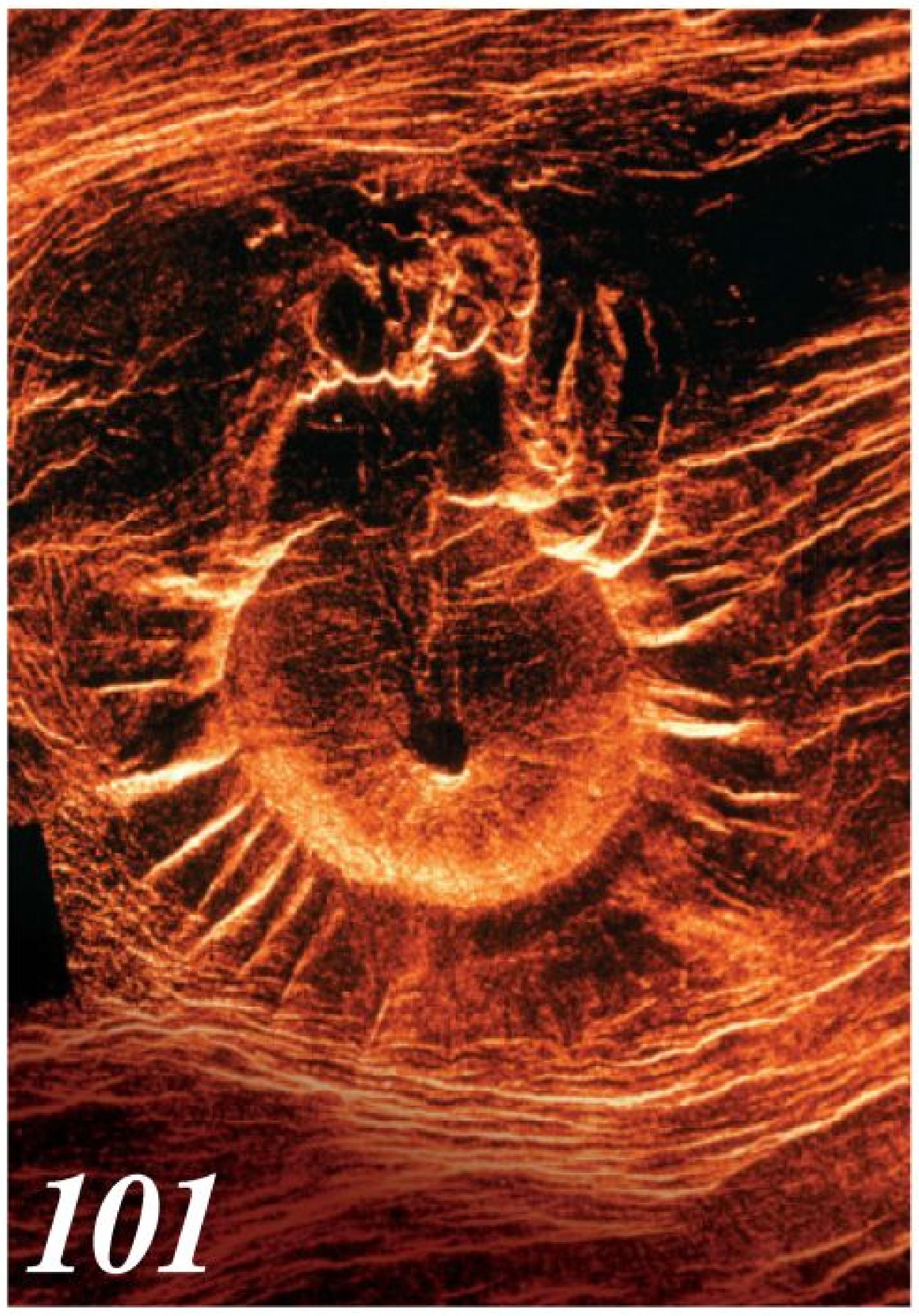

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> "Covering thousands of miles across land and sea, migrations are one of nature's true tests of endurance"

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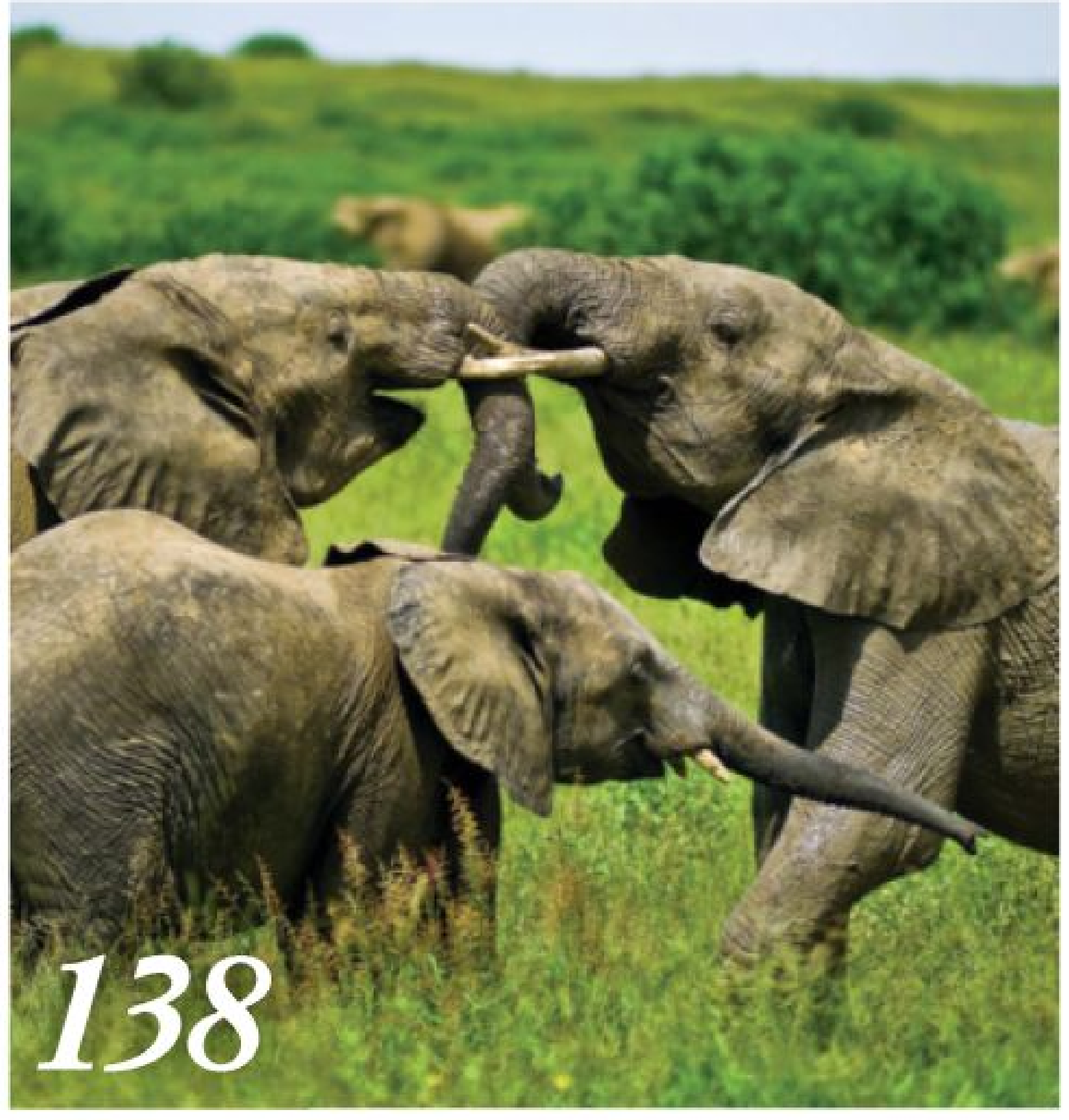
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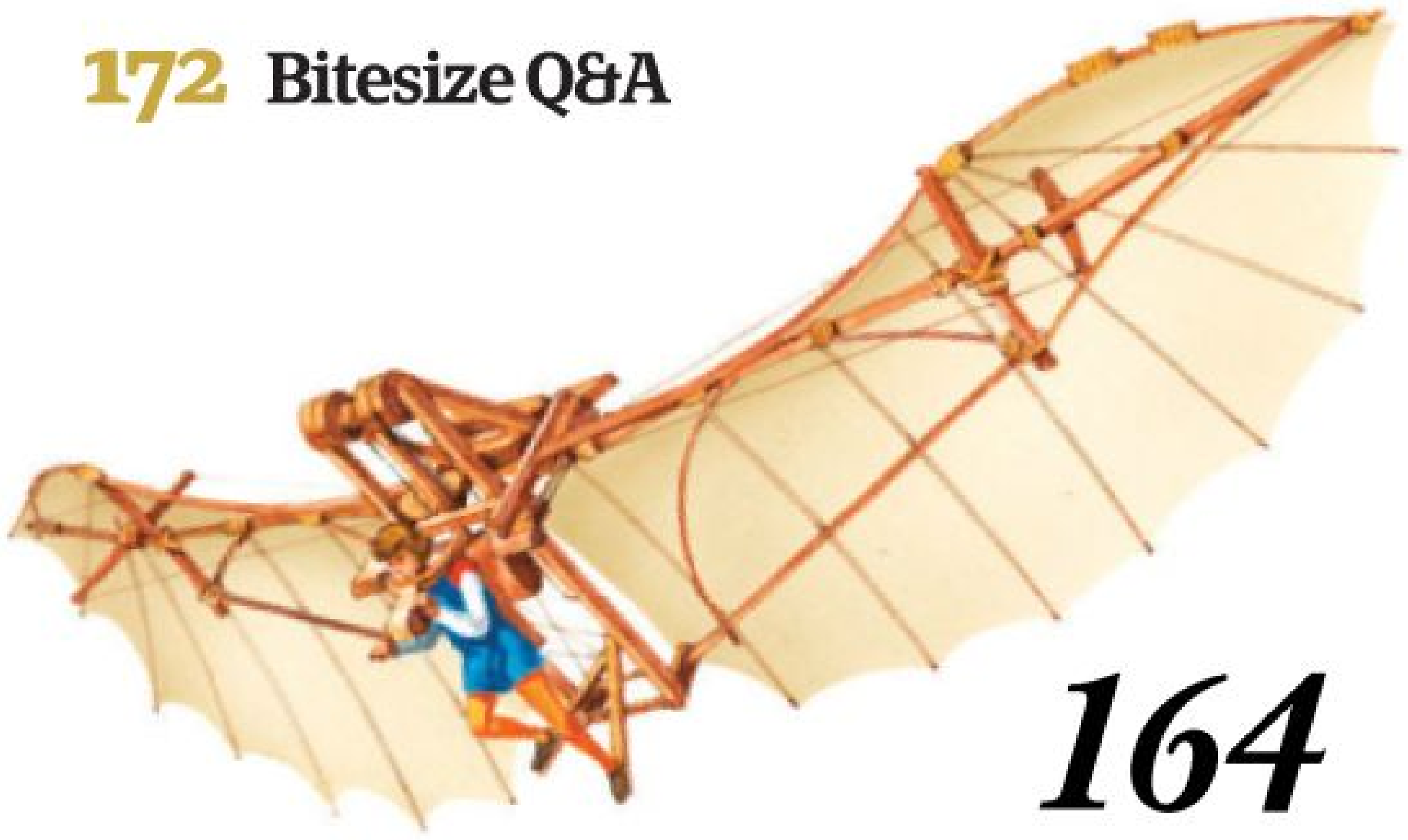
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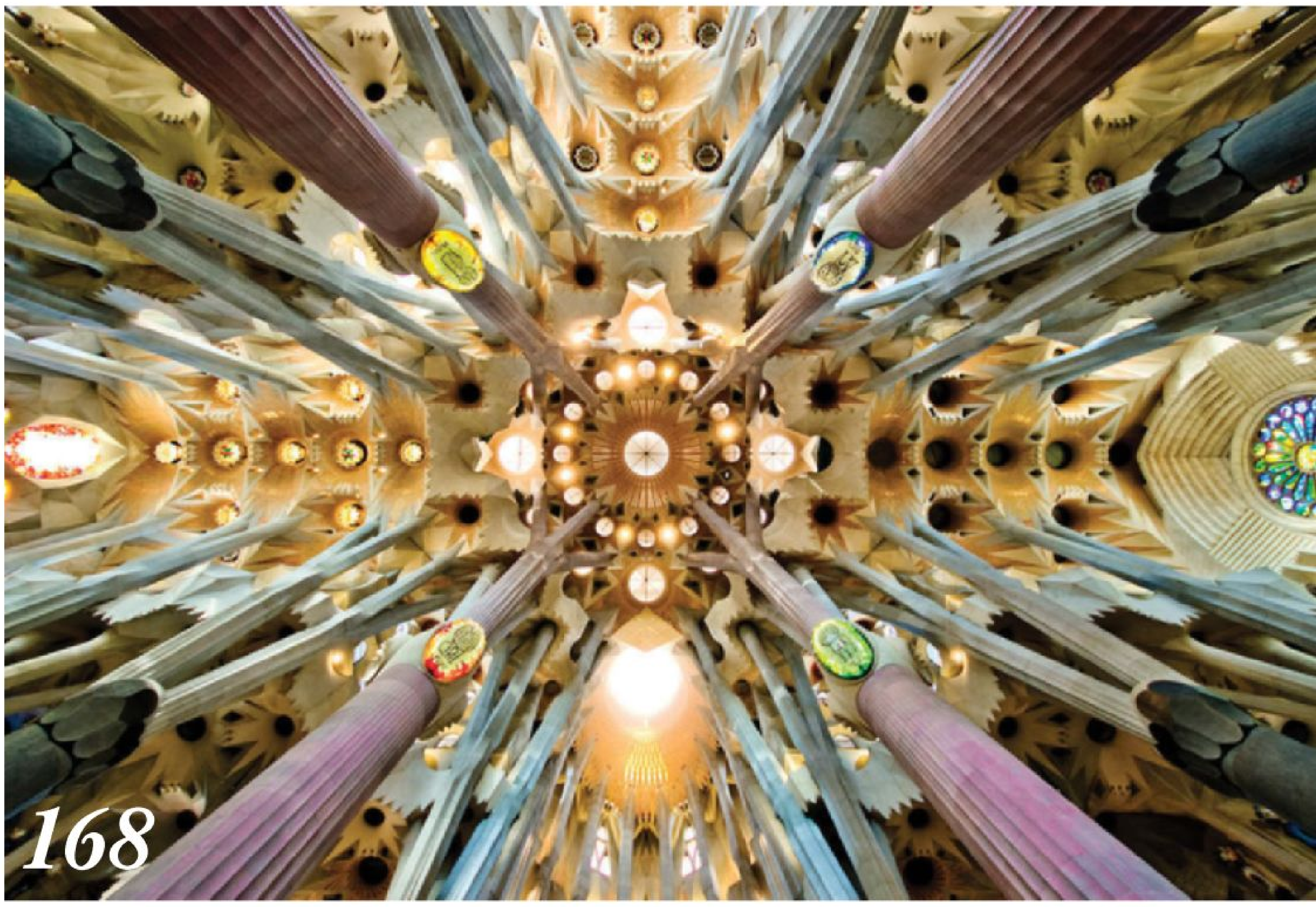
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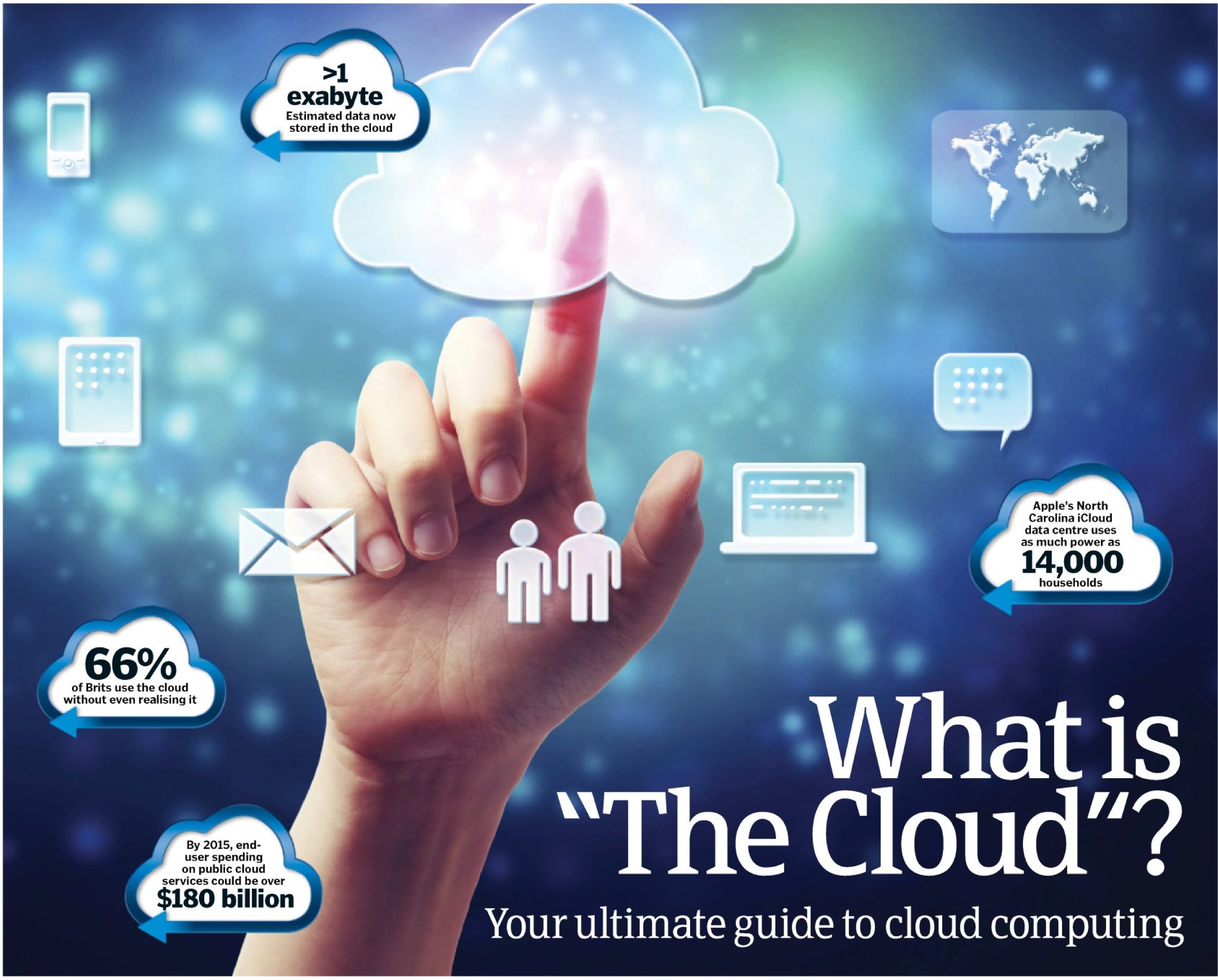

>1 exabyte
Estimated data now stored in the cloud
Apple's North Carolina iCloud data centre uses as much power as 14,000 households
66% of Brits use the cloud without even realising it
By 2015, end-user spending on public cloud services could be over $180 billion

What is "The Cloud"?

Your ultimate guide to cloud computing

The cloud” is a major buzzword in computing right now, but its meaning is rather, well, cloudy for most people. Nevertheless, chances are high that you've already used the cloud for storing data and files, even if you may not have known it at the time. Media sharing services like Flickr, Instagram and YouTube? They use the cloud. Webmail clients like Gmail and Hotmail? Banking apps? Those too. Read on and we'll see if we can't dispel the fog a little...

At its heart, cloud computing involves using the power of the internet to outsource tasks you might traditionally perform on a personal computer – this could be anything from handling simple storage to complex development and processing – to a vast and powerful remote network of interconnected machines.

This outsourcing is handy for the average, casual user who is simply fed up of having to free up space on their hard drive on their computer or mobile device or purchase new storage for all the cat/baby/food photos they can't stop taking. It's even better for businesses that want to use the cloud for processing and storage – because users only pay for what they use.

Think about it. Back in the day, companies purchased computing infrastructure based on what they figured they might need now and in the next couple of years. Fearing what would happen if they underestimated demand, they tended to over-buy only to then have the equipment sit around idle. Not only that; business software is expensive. Not to mention the servers, networks, bandwidth, power, cooling, office space, and the experts needed to install, configure and run the whole caboodle.

Cloud computing allows businesses to run essential programs and applications through the Internet, which will often mean saving them a whole lot of time, space, hassle and lots and lots of money. Billing for cloud services works just like the way you pay for utilities like gas and electricity in your home; it's pay-as-you-go.

The cloud is also flexible for users. For heavy tasks, clients have instant access to scaled-up computing power on the fly. When they're done with it they simply release it back to the cloud.

What is the cloud?

The first thing you need to know is that "the cloud" exists in far-flung data centres, which you access via the internet. It is basically a collection consisting out of networked computer hardware that works together to provide many aspects of computing in the form of online services. You can't physically touch the hardware itself in the public cloud, but you can control it remotely via web interfaces.

One of the central features of the cloud is virtualisation. Virtual machines are created with software that subdivides the computing power, memory and storage of a given machine into multiple smaller units, each running their own operating system. This virtualisation allows computing resources to be shared and allocated efficiently across the cloud.

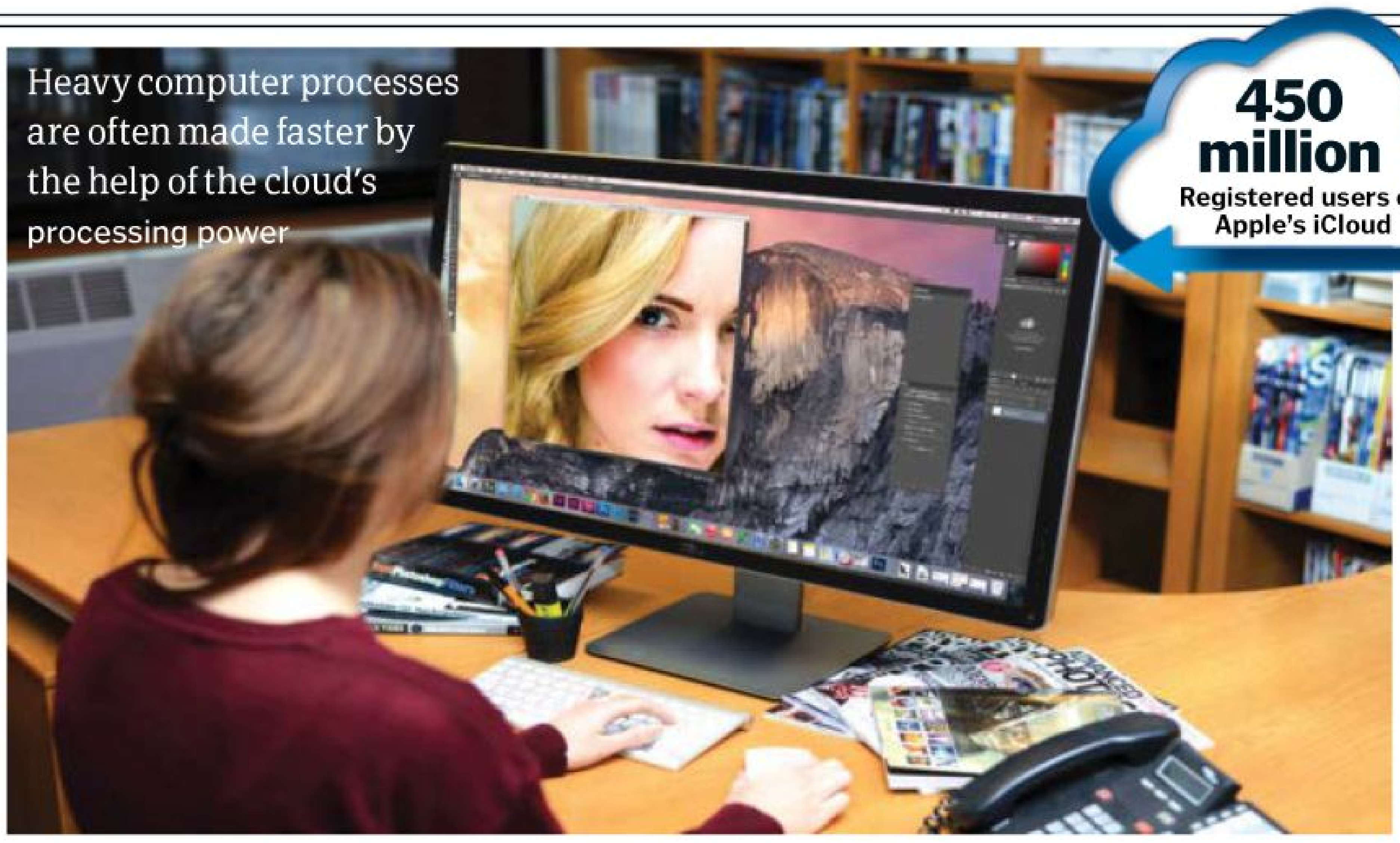
Cloud computing is a general term that is better divided into three categories: Infrastructure as a Service (IaaS) – where big players like Amazon and Google rent out immense computing infrastructure to other companies; Platform as a Service (PaaS) – online spaces where developers create online applications for specific sets of users; and Software as a Service (SaaS) – where clients use software over the internet.

Even the average web surfer at home has interacted with at least some of these. Facebook, Twitter and Gmail are all examples of SaaS cloud applications. One of the things that make it so powerful is the fact that – in the case of the former two – thousands, even millions, of people can interact with the same bit of information simultaneously.

The other giant boon for individual users is that services like Dropbox and Apple's iCloud allow them to store their photos, email, music, calendars, contacts and other data in a central location, accessible from whatever device happens to be handy. These can be set up to automatically sync with the cloud, ending an era of fumbling with USB cables and cursing yourself for bringing the wrong data stick to a meeting. Relax! That appointment you just noted in your phone will appear seamlessly in your desktop calendar, leaving you free to kick back and enjoy the music you're streaming from your collection on distant servers.

> "Cloud computing involves using the power of the internet to outsource tasks you'd perform on a computer"

14 million
Jobs cloud computing has created by 2015



Heavy computer processes are often made faster by the help of the cloud's processing power

450 million
Registered users on Apple's iCloud

Cloud storage vs cloud computing

Cloud storage involves stashing forms of data (pictures, documents, etc) on hardware in a remote physical location, which can be accessed from any device via the internet. Clients send files to a data server maintained by a cloud provider instead of (or as well as) storing it on their own hard drives. Dropbox, which lets users store and share files, is a good example. Cloud storage systems generally encompass hundreds of data servers linked together by a master control server, but the simplest system might involve just one.

Cloud computing also involves clients connecting to remote computing infrastructure via a network, but this time that infrastructure includes shared processing power, software and other resources. This frees users from having to constantly update and maintain their software and systems, while at the same time allowing them to harness the processing power of a vast network. Familiar everyday services powered by cloud computing include social networks like Facebook, webmail clients like Gmail, and online banking apps.

Cloud jargon buster!

1 Server
A computer that processes requests and delivers data to client computers over a local network or the internet. Typically configured with extra processing, memory and storage, it lets clients share data.

2 Data centre
A purpose-built facility that houses cloud infrastructure such as servers, storage and networking.

3 Virtualisation
Where single servers are made to think they're multiple servers with independent operating systems – reducing the amount of machines.

4 Redundancy
The additional machines built in cloud-computing systems to make back-ups and cover for a failure in the systems' main machines.

5 Elasticity
The characteristic that allows cloud systems to automatically scale up or down the provision of resources to meet current demand.

6 SaaS (Software as a Service)
Software or applications that are accessed over the internet and require no end-user installation. Examples include webmail services like Gmail.

7 PaaS (Platform as a Service)
A tool-rich environment where software developers create, customise, test and deploy applications.

8 IaaS (Infrastructure as a Service)
Computing infrastructure such as memory, storage, processing and networking, which users purchase based on consumption instead of having to buy hardware outright.

Where's my stuff?

Two words: data centres. Anything you've uploaded to the cloud, or run from the cloud, exists on dedicated servers and storage volumes housed in vast warehouses. Data centres are owned by cloud service providers responsible for keeping the servers up and running.

The job of all data centres, however big or small – and yes, some of them can be tiny – is to keep your data physically safe from theft and destruction, and to make sure it's available whenever you want to access it. They run extensive cooling systems to keep the electronics from overheating and have at least one backup generator in case of power outages.

Once you've put your data in the cloud, it may be physically stored in many different places, countries or even continents, depending on where the service provider's data centres are located. In fact, cloud providers actually make multiple copies of the data you upload and purposely store these in disparate locales to ensure that it won't get destroyed or be inaccessible in the event that a natural disaster takes out one of the centres.

The physical location of their stored data is irrelevant to the majority of people, since it can be called together over the internet almost instantly. But for organisations using the cloud for certain sensitive types of data – government documents or health records, for example – understanding where the data is headed and which data-protection and privacy laws apply in those places becomes critical.

How safe is the cloud?

The cloud may promise to lift the burden of our ever-increasing data storage needs, but how do we know our data is truly safe when we entrust it to a cloud provider? What measures do they take to address our two biggest concerns: reliability and security?

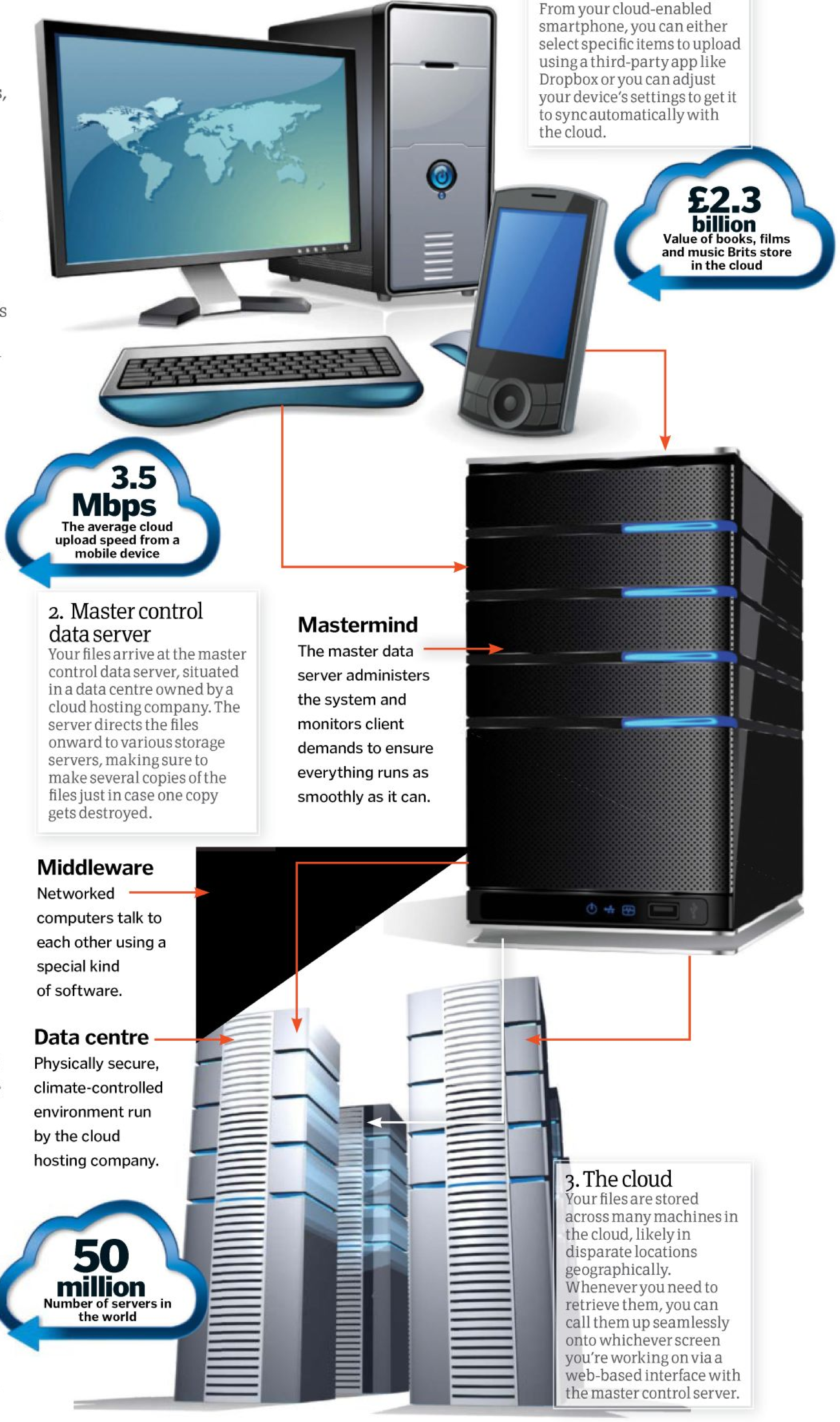
We've already learned that cloud providers store backups in multiple locations. Systems that detect smoke, suppress fires and provide emergency power are also standard features of data centres, and these secret locations are heavily reinforced, guarded and internally protected to prevent intruders or disgruntled employees from physically harming or stealing the storage hardware.

To secure your data so no one else can get at it without your permission, cloud systems use authentication processes like usernames and passwords to limit access, and data encryption (see boxout below) to protect data that is stolen or intercepted en route. And yet, passwords can be hacked; often it's the service provider who holds the encryption keys to your data, meaning that rogue employees could access it; and your data isn't immune to search and seizure by government entities.

So, to entrust or not to entrust? In any case, you can rest assured that – since cloud storage companies live and die by their reputation – they take great pains to employ the most advanced security techniques for the most reliable service possible. But the bottom line is that we live in an ag where national governments have been exposed for tapping into supposedly private cloud data. Savvy surfers would be wise to keep anything truly sensitive stored on their personal computer or private cloud behind a firewall, and never upload it to the public cloud. ✿

Head in(to) the clouds

Where do your photos, appointments, and music actually go when they leave your phone?



1. Device upload

Keeping your data backed up, neatly organised and accessible on the go is easy. From your cloud-enabled smartphone, you can either select specific items to upload using a third-party app like Dropbox or you can adjust your device's settings to get it to sync automatically with the cloud.

£2.3 billion
Value of books, films and music Brits store in the cloud

3.5 Mbps
The average cloud upload speed from a mobile device

2. Master control data server

Your files arrive at the master control data server, situated in a data centre owned by a cloud hosting company. The server directs the files onward to various storage servers, making sure to make several copies of the files just in case one copy gets destroyed.

Mastermind
The master data server administers the system and monitors client demands to ensure everything runs as smoothly as it can.

Middleware
Networked computers talk to each other using a special kind of software.

Data centre
Physically secure, climate-controlled environment run by the cloud hosting company.

50 million
Number of servers in the world

3. The cloud

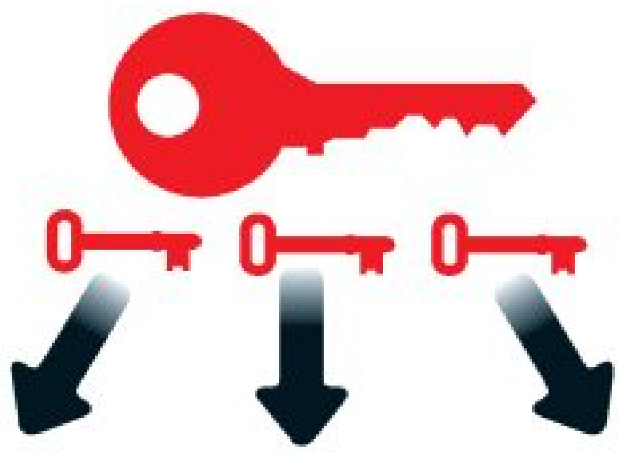
Your files are stored across many machines in the cloud, likely in disparate locations geographically. Whenever you need to retrieve them, you can call them up seamlessly onto whichever screen you're working on via a web-based interface with the master control server.

How data encryption works

Public-key encryption uses a combination of cryptographic keys to keep your data safe

1.5 million Requests Amazon's S3 storage service processes per second

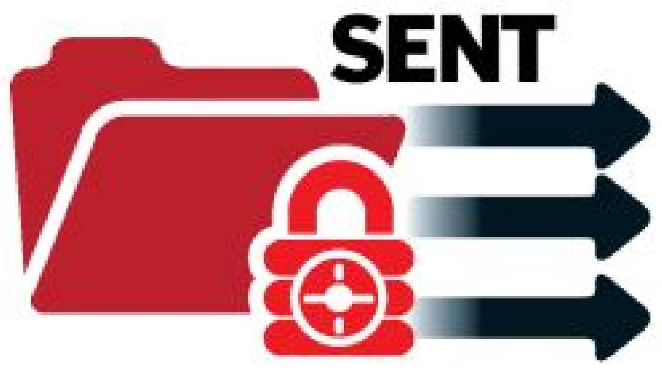
1 Public-private key pair Your device owns two cryptographic keys that are mathematically related: one is public, the other is private.



2 Key hand-out It then makes your public key freely available to any other other computer that wants to send a file to the computer you're using.

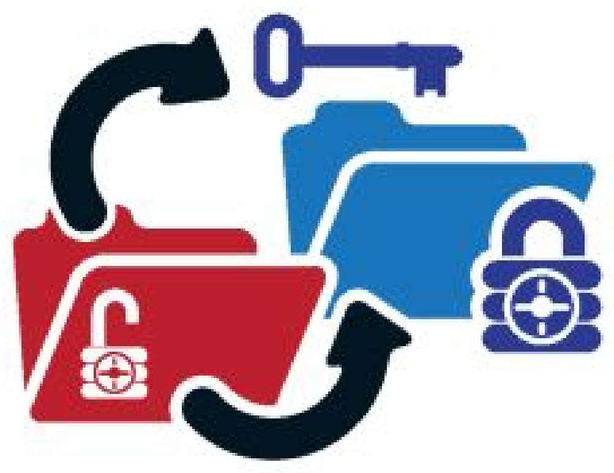
3 Encryption When someone sends you a file, their computer encrypts it with a symmetric key, meaning it can only be opened with the identical key.

4 Public key encryption Both the encrypted file and the key needed to decode it are placed in a file and encrypted using the public key.



5 File transfer During the file transfer process the public-key encrypted file, image, or message is sent to the computer that you're using.

6 Decryption step 1 Data encrypted by public keys is decrypted by private keys; even if it's picked up by a device that knows your public key, only yours can decrypt it.



7 Extraction Your computer extracts the encrypted file and the symmetric key needed to decode it.

8 Decryption step 2 The computer then continues to decode the file at hand using the symmetric key.

9 File unlock Voila! The contents of the file are decrypted, and now yours, and yours only, to view.

How was the iCloud hacked?

On 31 August 2014, a cache of almost 200 personal photos of celebrities – many of them explicit – was posted online. *X-Men* and *Hunger Games* star Jennifer Lawrence and recording artist Rihanna were among those whose private pictures, taken on their iPhones and automatically backed up to the iCloud, were stolen and distributed. Following the attacks, one survey found that 20 percent of respondents were less confident in the security of the iCloud, while 40 percent were worried about storing photos and data in a cloud service. How did this security breach happen?

In an interview in the *Wall Street Journal*, Apple CEO Tim Cook dispelled rumours that the victims' user IDs and passwords were taken from their servers in a brute force attack. Instead, he explained, the hackers obtained the info via a combination of phishing emails and correctly answering the celebrities' security questions. "That's not really an engineering thing", he commented, but conceded that Apple should have done more to make users savvier about choosing strong passwords and protecting themselves.

Since the scandal, Apple has beefed up its security measures by expanding its two-factor ID verification system to include when a new device tries to access iCloud data. Users will also receive an email alert or push notification whenever someone tries to do these things or change the password. Apple encourages iCloud users, the majority of whom haven't enabled two-factor authentication, to turn on the feature.

Jennifer Lawrence was one of over a hundred female celebrities to have personal photos stolen from their iCloud accounts

Keeping your data safe

Apple's two-factor verification prevents others from accessing your account and your personal files, even if they do know your password.

my.name@icloud.com

••••••••••••••••

Sign in

Whenever you sign into iCloud, or make a purchase in iTunes, iBooks or the App Store, you are asked to enter your Apple ID and password for confirmation.

Added layer

If you're signed up for two-factor, Apple sends a four-digit verification code by SMS or Find My iPhone to one of the trusted personal devices you've registered.

1 2 3 4

Verification

Entering this code into the browser verifies your identity and completes the sign-in process, allowing you to securely access your account and make purchases as usual.

© Dreamstime; Startraks Photos/Rex Features

How are bridges built?

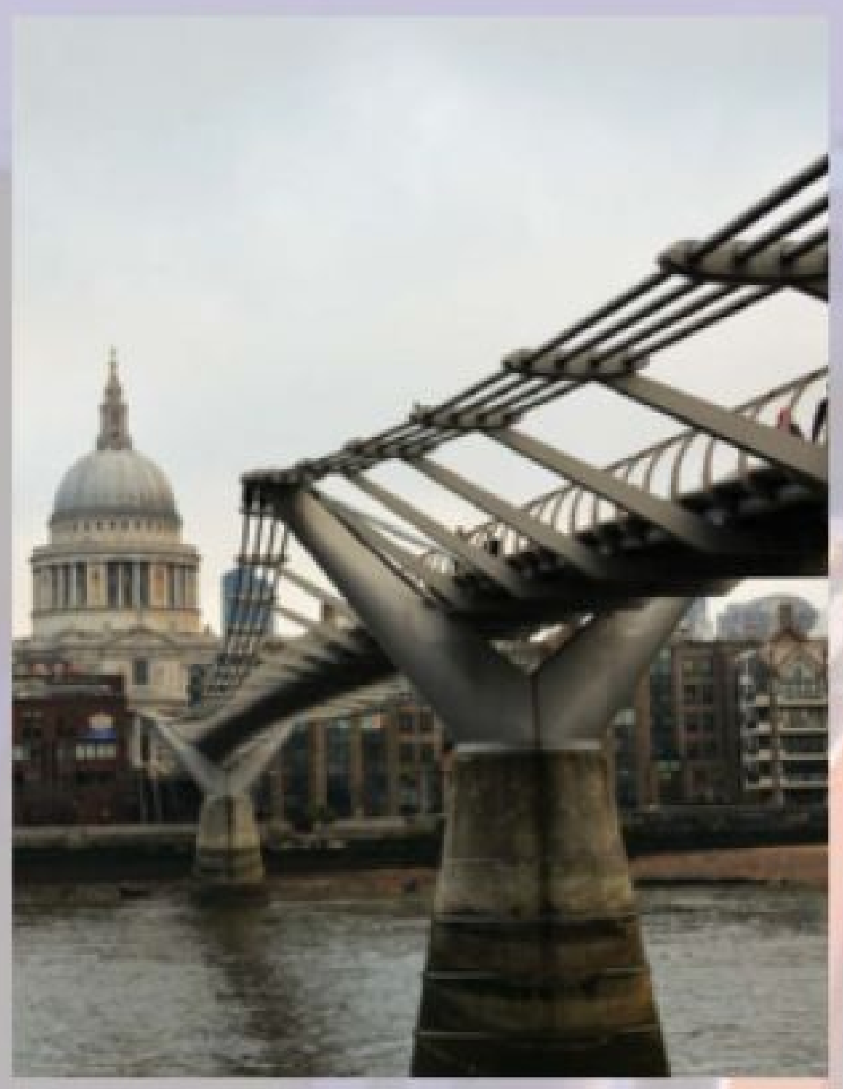
The design and technology behind these fundamental structures

All over the globe, bridges come in many shapes and sizes. The humble structure was born by simply balancing a horizontal beam across two pillars. However, as demand grew, wider gaps needed to be crossed and more weight had to be carried. This created the need for arches. Utilised by the Ancient Romans, the arch shape could hold massive amounts of weight and was a revelation in creating larger and stronger bridges. However, arches could only reach a certain length. To cross larger expanses, even longer bridges have to be constructed. These are called suspension bridges. These work using a combination of compression and tension forces that run through a cable system. The road or 'deck' is laid out across these cables, which are strung together with the correct balance of the two forces so it won't buckle or snap under pressure. On most suspension bridges, a tower is placed at either end to take the strain and weight. Iconic examples of these bridges include the Golden Gate Bridge in San Francisco and England's Humber Bridge. Away from the road, bridges are also used for rail and water transport. These bridges are often even longer and stronger as they have to ferry water or huge freight and passenger trains or ferries over vast distances. Seven of the ten longest bridges in the world are located in China, with most of these being rail bridges. As technology and engineering improves, even-more expansive bridges could be in the pipeline. There has been talk of a bridge between England and France and a crossing through the Strait of Gibraltar connecting Europe and Africa. Although it may seem far-fetched, the 16-kilometre (ten-mile) Øresund Bridge that links Denmark and Sweden has demonstrated that cross-country bridges can be constructed successfully.

The Millennium Bridge

Why this famous London structure started swaying

When a new bridge is designed and built, it is essential that all of its construction calculations are absolutely correct. If they are even slightly out, the entire structure could become perilously unstable. Take the Millennium Bridge in London, for instance. Opened in 2000, the bridge experienced sudden and very dangerous sideways movements after the huge crowds who crossed it caused it to sway under the pressure. The eventual solution was to use 91 dampeners underneath the bridge, which absorbed the kinetic energy of the pedestrians' movement and prevented it from wobbling. It reopened fully fixed in 2002 but at a cost of over £5 million ($8 million). An expensive mistake!



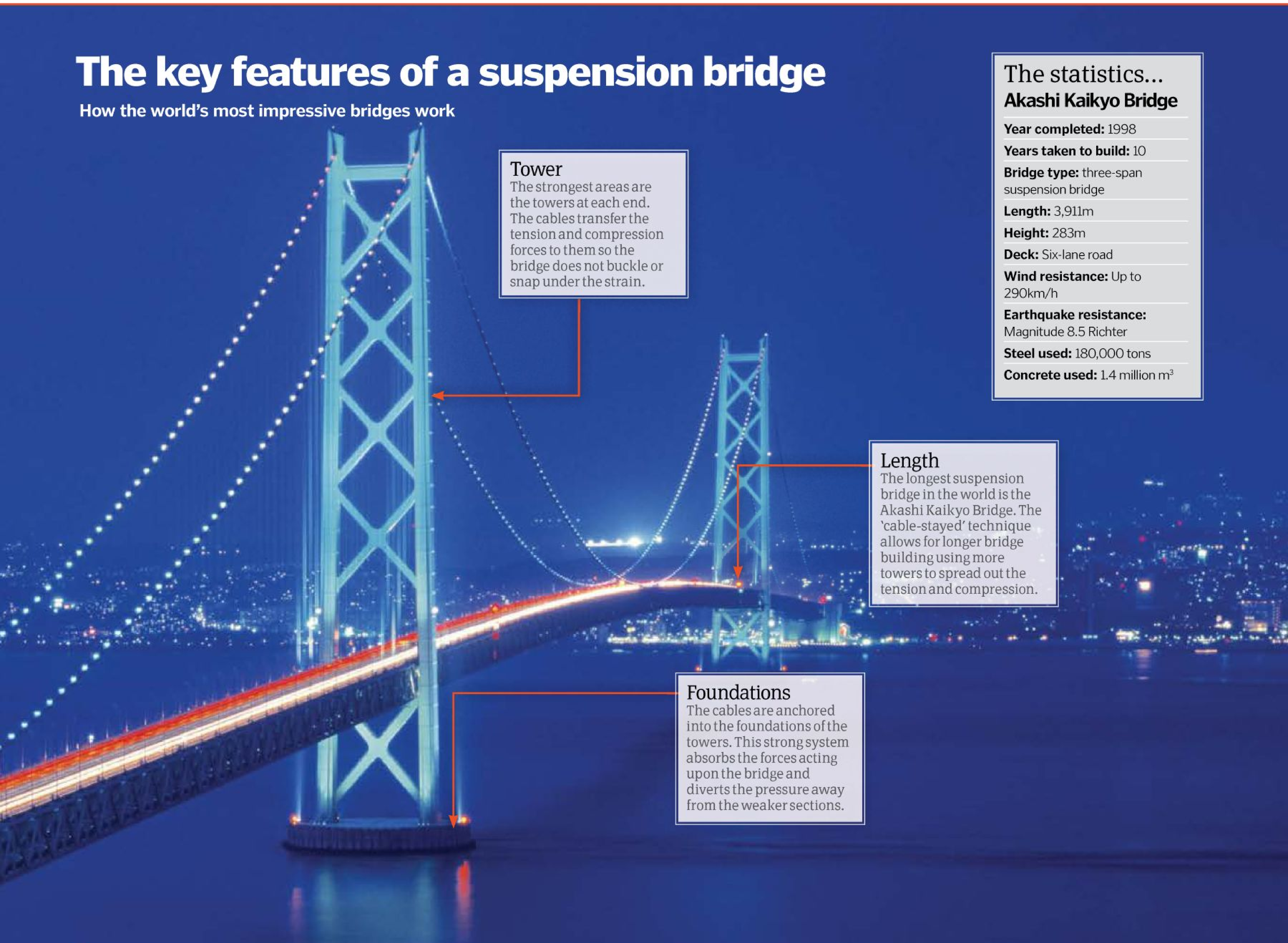
Compression and tension
The sheer length of suspension bridges means many forces act upon it. The bridge's job is to balance the forces and transfer them to a stronger area that can handle the pressure.

Deck
The deck can be made to suit road, rail or even water. It is strengthened by a truss that runs underneath the highway, allowing heavier weights to be transported across.

> "When a new bridge is made, it is essential that all of its construction calculations are correct. If they are even slightly out, the structure could become unstable"

The key features of a suspension bridge

How the world's most impressive bridges work



Tower
The strongest areas are the towers at each end. The cables transfer the tension and compression forces to them so the bridge does not buckle or snap under the strain.

Length
The longest suspension bridge in the world is the Akashi Kaikyo Bridge. The 'cable-stayed' technique allows for longer bridge building using more towers to spread out the tension and compression.

Foundations
The cables are anchored into the foundations of the towers. This strong system absorbs the forces acting upon the bridge and diverts the pressure away from the weaker sections.

The statistics…

Akashi Kaikyo Bridge

Year completed: 1998

Years taken to build: 10

Bridge type: three-span suspension bridge

Length: 3,911m

Height: 283m

Deck: Six-lane road

Wind resistance: Up to 290km/h

Earthquake resistance: Magnitude 8.5 Richter

Steel used: 180,000 tons

Concrete used: 1.4 million m^3

Types of bridge

The many ways to bridge and cross a gap

Arch

One of the oldest methods of bridge building, the arch bridge is made by compressing stone, steel and concrete with the finished arch working as a wind bracer. They can range from small brick designs to tall and extensive metal constructions.

Suspension

This type is made of steel plates and cables. Suspension bridges use a combination of tension and compression, which is carried by the cables to towers at either end. Cables transfer weight to the towers. Their light weight allows them to span long distances.

Beam

Made out of wood or iron, beam bridges are the simplest type of bridge construction. The weight is put on two support girders on either side of the crossing. The earliest examples of beam bridges came in the form of humble logs or tree trunks across streams.

Cable-stayed

The cable-stayed bridge is one of the most common in contemporary bridge building. They have one or more towers, each of which uses vertical compression to move the forces from the cables through to the foundations, reducing the strain.

Bascule

Also known as a drawbridge, it ranges in size from a medieval feature to larger structures like Tower Bridge. Usually powered by a counterweight and winch, similar designs include a vertical-lift bridge and a swing bridge that can pivot.

© Rich Niewiroski Jr; Thinkstock; Corbis

Will growing plants without soil reduce pollution?

Hydroponic systems already grow tomatoes and lettuce, and might one day produce new superfuels

Hydroponics is a system of growing crops in nutrient-enriched liquid baths rather than soil. Normally, roots anchor the plant in the ground and absorb all the water, minerals and nutrients from the soil the plant needs in order to grow. They cannot break down the soil particles but rely on the dissolved solution between them.

Hydroponics does away with soil and grows plants with their roots suspended in an aerated nutrient solution in greenhouses. The roots can also be supported in an inert medium, like gravel or sand, and flooded with a fertiliser solution. Tomatoes, cucumbers and peppers grown hydroponically in greenhouses in American deserts produce five to ten times as much crop weight per year as those grown in open fields.

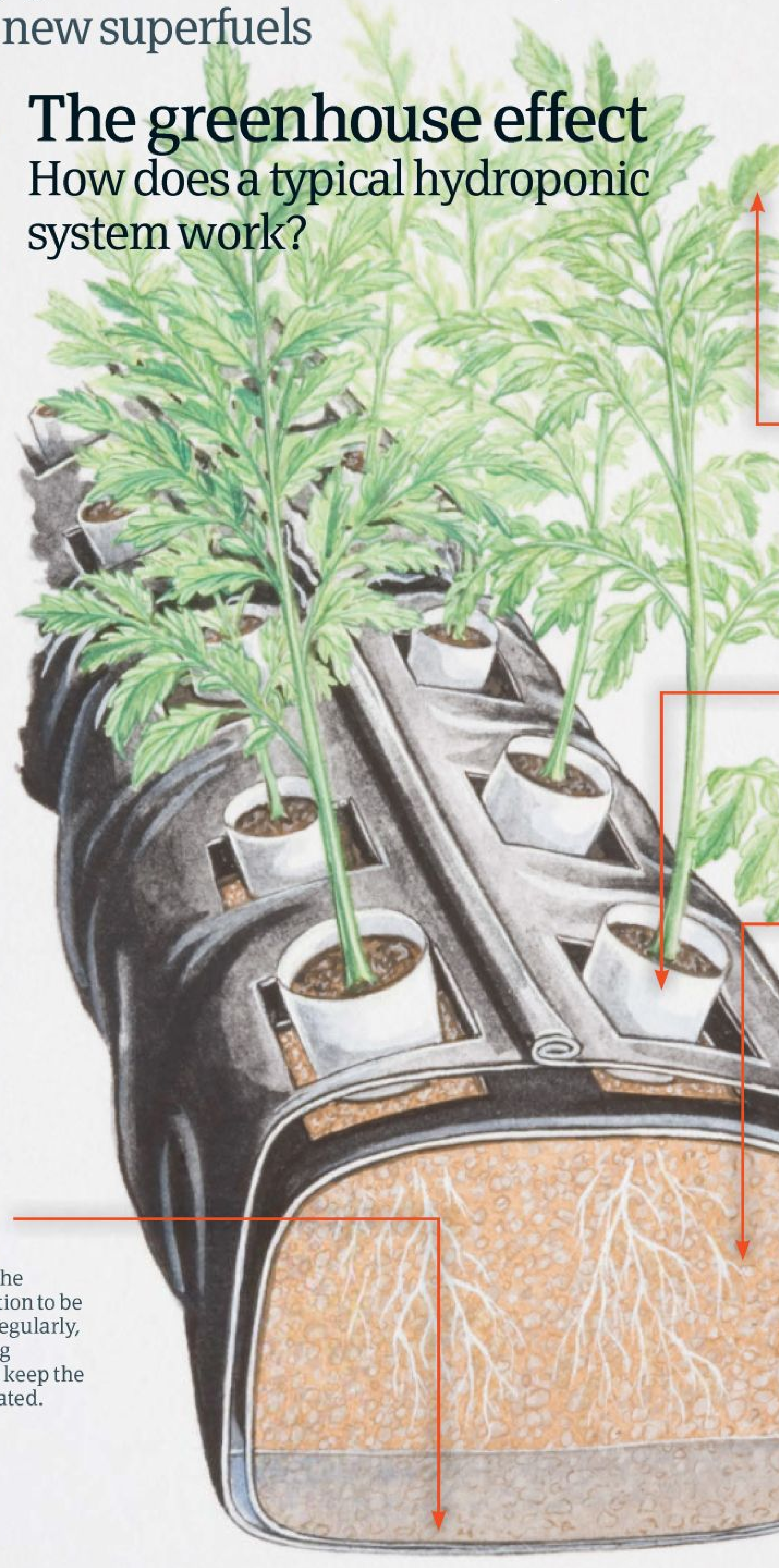
A new use is being developed for hydroponics. Algae (much simpler plants) are grown in tanks in the sunshine, absorbing CO_2 from the atmosphere as they grow. They develop 20 times as fast as traditional crops, so a portion can be harvested every day. This is fermented to produce ethanol and the mush left behind is buried. This process locks up carbon dioxide, helping to reduce greenhouse gases that cause climate change.

Growth spurt

- THE IDEAL CONDITIONS FOR GROWTH
- RAINWATER IS AN IDEAL SOURCE
- 25°C (77°F): OPTIMUM TEMPERATURE
- PLENTY OF OXYGEN IS NEEDED
- FRESH NUTRIENTS EVERY WEEK
- PH LEVELS SHOULD BE BETWEEN 5 AND 6

The greenhouse effect

How does a typical hydroponic system work?



The greenhouse environment
The sunlight that plants need for photosynthesis shines through the greenhouse glass, which also protects the plants from damaging winds.

Tomato plants
Tomatoes are especially well suited to hydroponic cultivation. They can produce yields as high as 75kg/m2 (15lbs/ft2) in a year.

Starter pots
In this system, the seedlings are germinated in small pots of soil, but soon their roots outgrow these pots.

Inert medium
The roots grow down through rockwool, clay, vermiculite, sand or gravel – an inert medium providing structural support, not nourishment.

Drainage channels
These allow the nutrient solution to be drained out regularly, to stop it going stagnant and keep the roots oxygenated.

Nutrient bath
A balanced solution of nutrients in water is poured into the inert medium to nourish the tomatoes' growth.

© Thinkstock

How does dialysis clean blood?

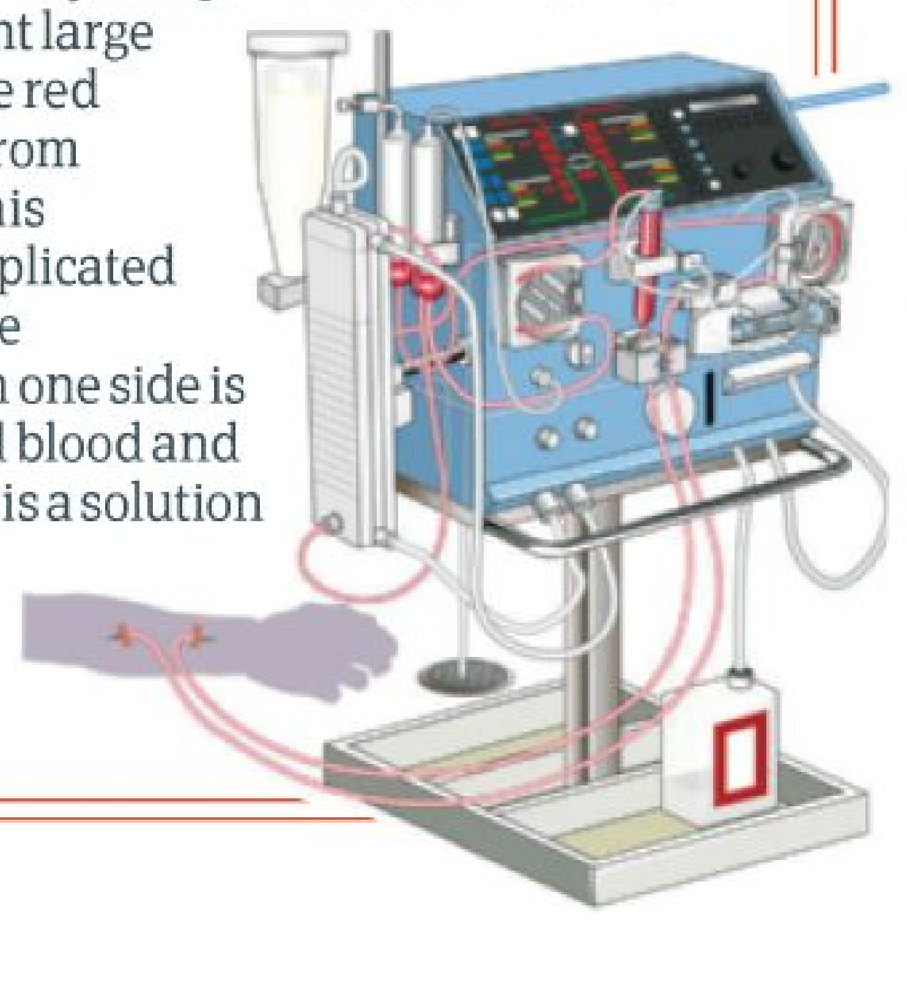
Discover how the amazing dialysis process rids your body of harmful waste

When kidneys fail to filter your blood of waste and unwanted water, we rely on dialysis. It takes the basic scientific principles of concentration gradients and diffusion to filter out harmful substances from the bloodstream. A dialysis machine can control which substances are removed and at what concentration, allowing fine control of waste product removal and electrolyte balance. Dialysis is needed when the kidneys' natural function is lost. Since you can live with one kidney, both need to be affected before dialysis is required. Common reasons for dialysis are severe diabetes and long-standing high blood pressure, while rare causes include genetic diseases.

Dialysis machines date back to the Second World War. Today there are two main types: haemodialysis, which filters the blood, and peritoneal dialysis, which filters fluid within the abdomen. While life-saving, dialysis needs to be performed up to four times a week and is not without complications. A kidney transplant offers the best chance of long-term cure, but the number of patients on transplant waiting lists far exceeds the number of donated kidneys, so dialysis remains a key part of keeping people alive.

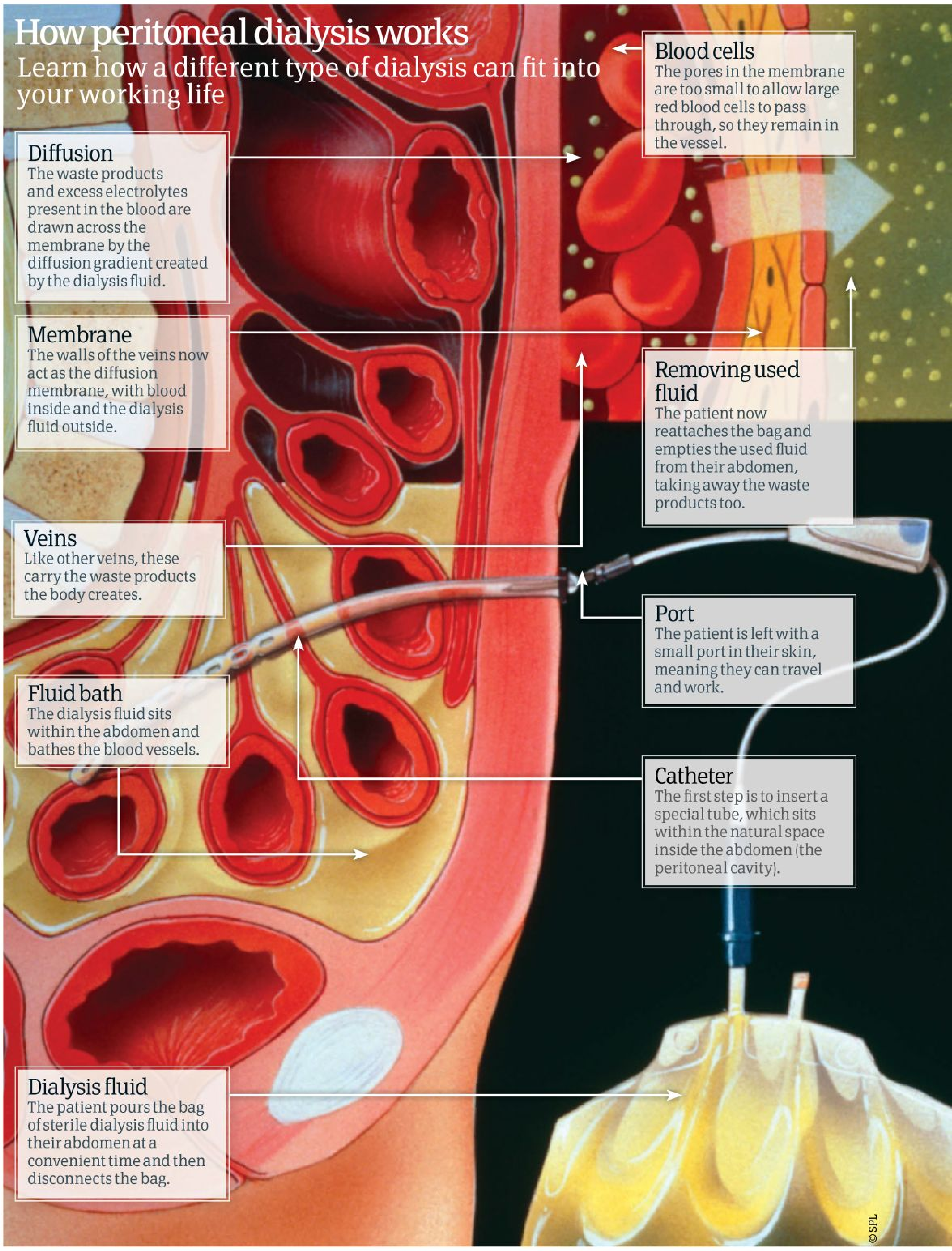
How a dialysis machine works

Sterile tubing is attached to a vein (to take blood away from the body) and an artery (to return cleaned blood). The process relies on a semi-permeable membrane, a thin sheet with tiny holes that only allows molecules under a certain size to pass through. On one side of the membrane is the blood, carrying nutrients and waste products. On the other side is the kidney, containing early components of urine. The pores prevent large particles like red blood cells from escaping. This process is replicated exactly in the machine. On one side is the removed blood and on the other is a solution that draws out the waste products.



How peritoneal dialysis works

Learn how a different type of dialysis can fit into your working life



Diffusion
The waste products and excess electrolytes present in the blood are drawn across the membrane by the diffusion gradient created by the dialysis fluid.

Membrane
The walls of the veins now act as the diffusion membrane, with blood inside and the dialysis fluid outside.

Veins
Like other veins, these carry the waste products the body creates.

Fluid bath
The dialysis fluid sits within the abdomen and bathes the blood vessels.

Dialysis fluid
The patient pours the bag of sterile dialysis fluid into their abdomen at a convenient time and then disconnects the bag.

Blood cells
The pores in the membrane are too small to allow large red blood cells to pass through, so they remain in the vessel.

Removing used fluid
The patient now reattaches the bag and empties the used fluid from their abdomen, taking away the waste products too.

Port
The patient is left with a small port in their skin, meaning they can travel and work.

Catheter
The first step is to insert a special tube, which sits within the natural space inside the abdomen (the peritoneal cavity).

© SPL

What's inside battle simulators?

A revolutionary new system for training the soldiers of tomorrow

Training recruits to use some of the world's most expensive and complicated military technology is no easy task. Millions of pounds' worth of military hardware needs to be placed in the hands of learners and, while these future fighters are carefully managed, the run-time costs to operate trial mission after trial mission are quite simply astronomical.

After years of development, defence company BAE has created a virtual battle training system – a simulation network that runs through live scenarios with several players simultaneously. Indeed, thanks to the Dedicated Engineering Network (DEN), simulators controlling virtual Type 45 destroyers, Typhoon fighter jets and even E-3D Sentry aircraft can be brought together in a simulated combat environment and put through their paces in a range of scenarios combining land, sea and air tech.

In doing this, not only can the most advanced military hardware be tested together as one functioning unit, but trainees and professionals alike can run through missions without even having to set foot outside.

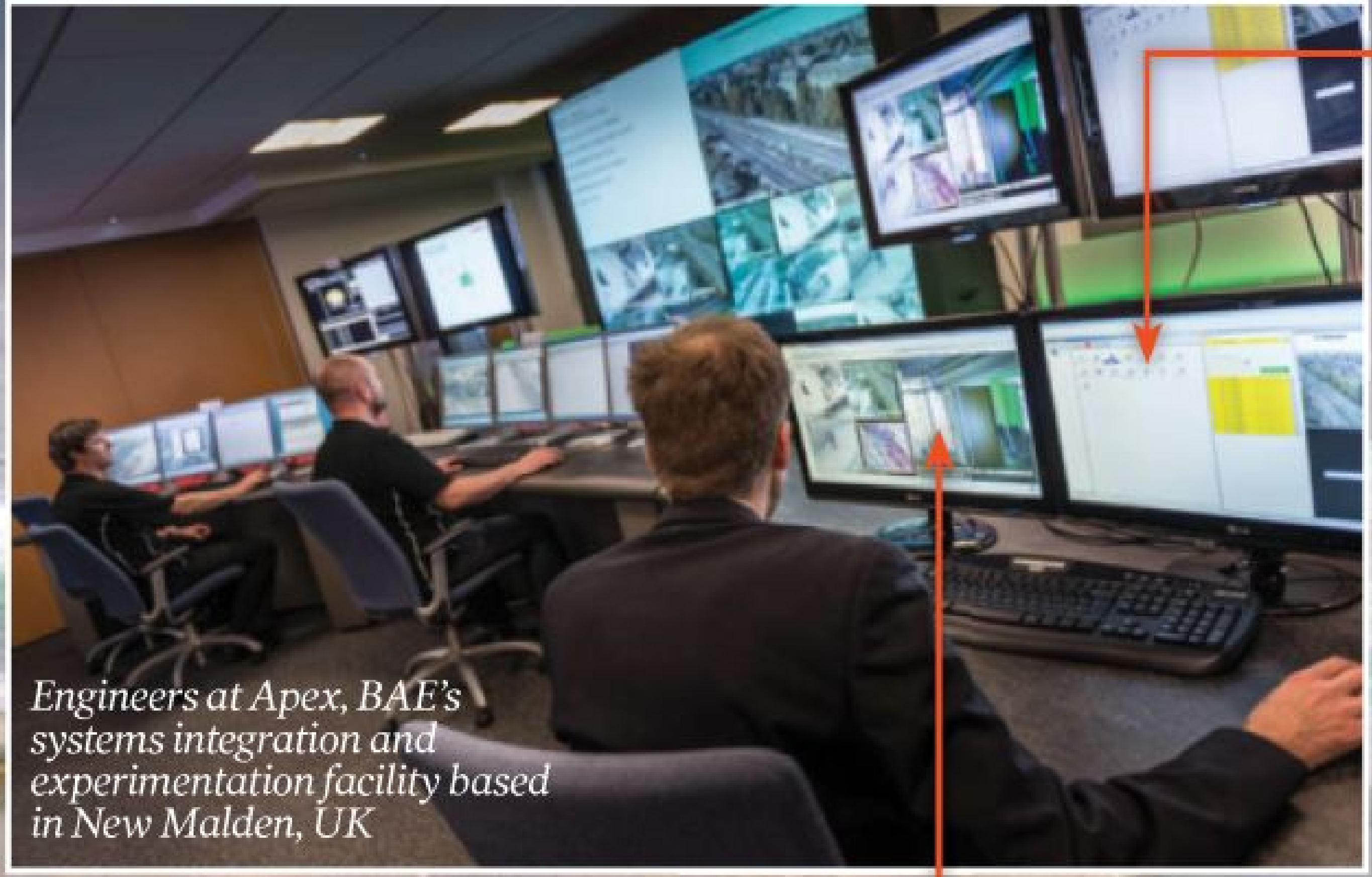
This not only saves money but also allows for a greater range of scenarios to be played out in a short period of time. Further, thanks to DEN securely managing integration with Ministry of Defence (MoD) networks, scenarios can be witnessed by commanders and decision-makers remotely, granting an unprecedented access to information.

The system is still under testing, with a simulator at BAE's Warton facility in Lancashire, UK, emulating four Typhoons, partnered with two other simulators at different sites which emulate an E-3D Sentry AEW1 and a Type 45 destroyer. With a high level of success to date, more trials are already planned, with more simulated combat vehicles looking to be integrated – the most notable being the state-of-the-art F-35 Lightning II fighter jet. ⚙

Two of the advanced military vehicles that soldiers can play out battle scenarios with using DEN

A digital battlefield

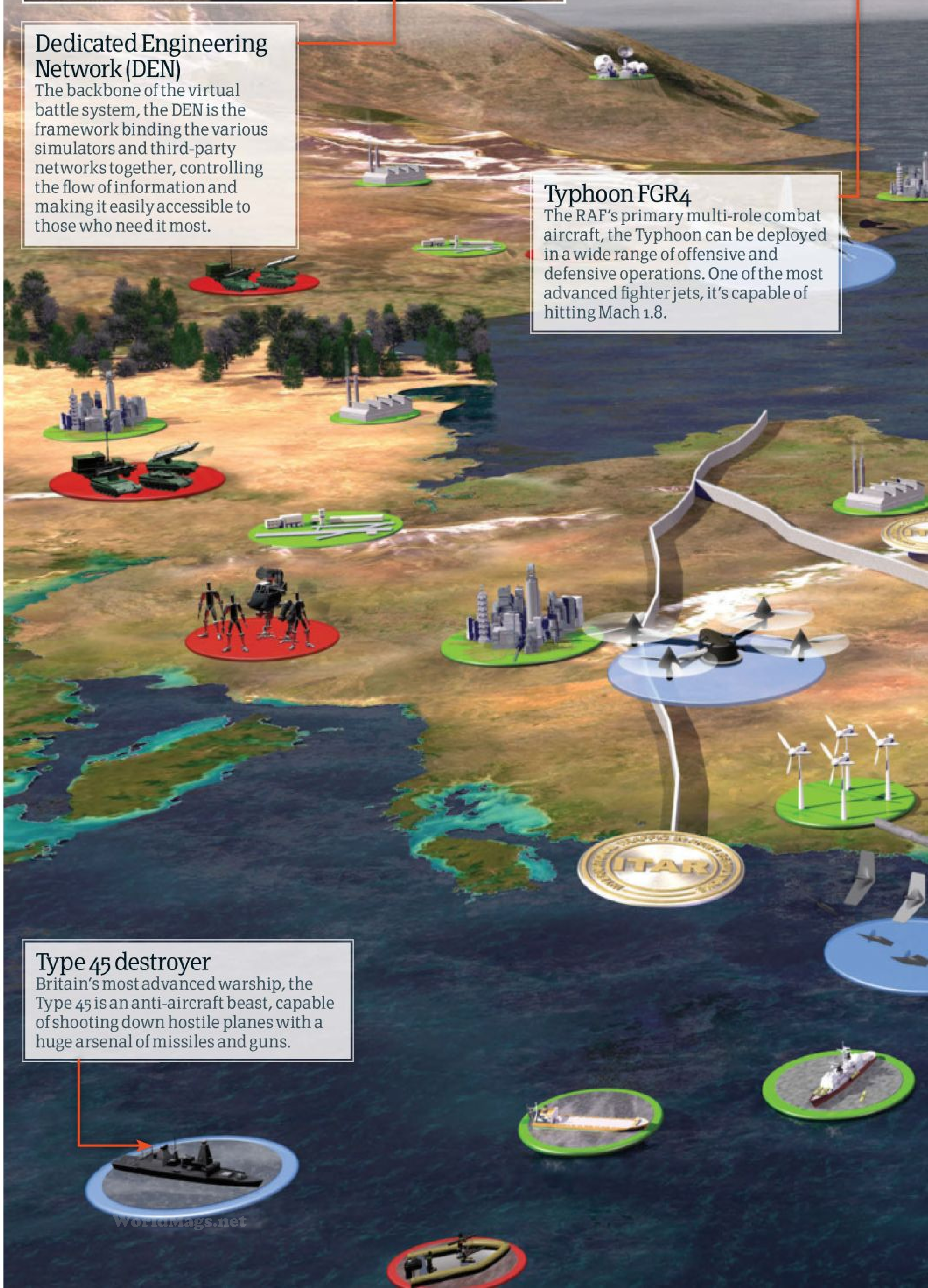
Check out the core elements that make up this country-wide combat simulator



Engineers at Apex, BAE's systems integration and experimentation facility based in New Malden, UK

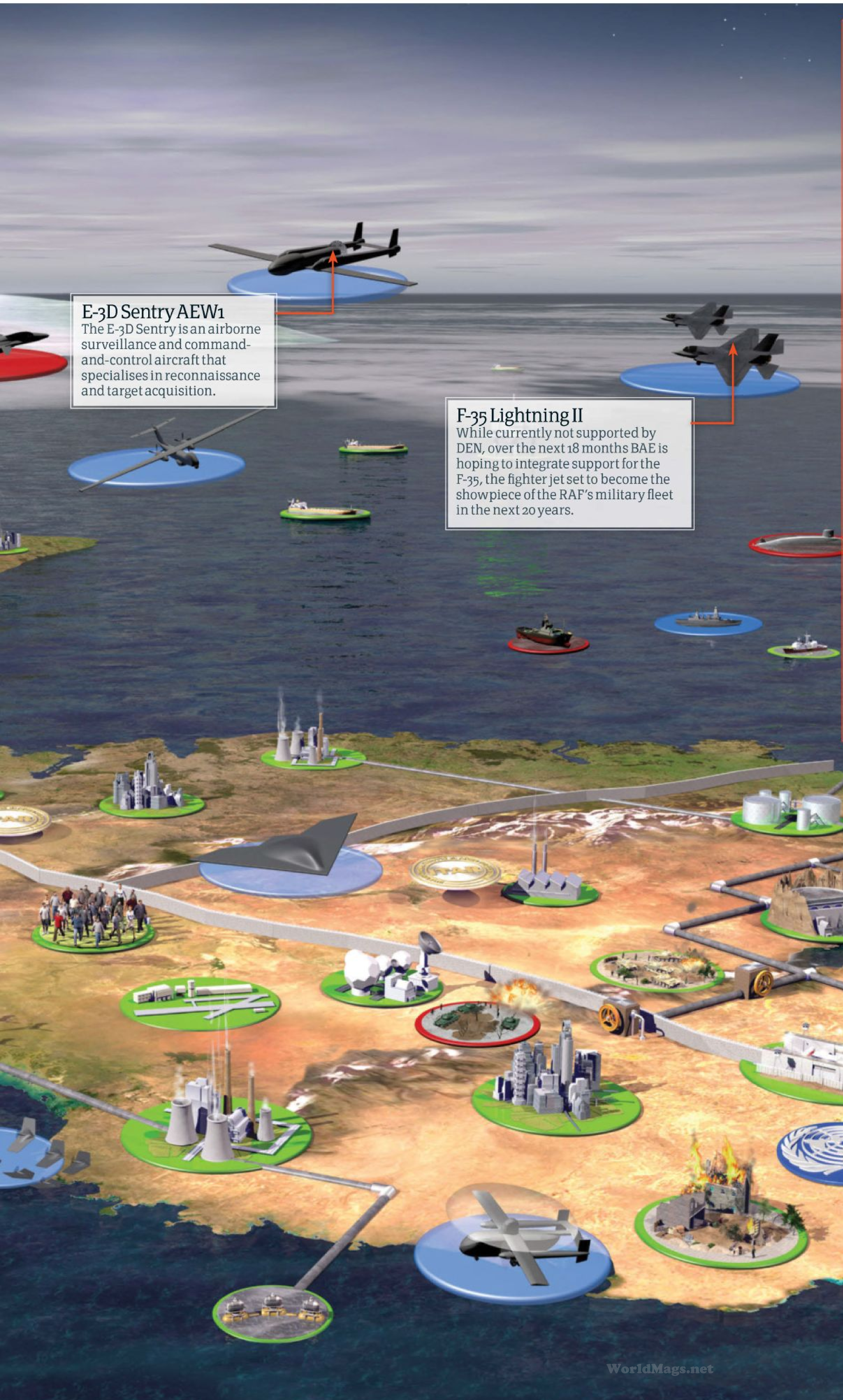
JMNIAN network
BAE's virtual battle system will be interoperable with the MoD's Joint Multi-National Interoperability Assurance Network (JMNIAN), which provides a hub for all of the armed forces. The DEN simulator can be accessed from numerous bases and defence facilities.

Dedicated Engineering Network (DEN)
The backbone of the virtual battle system, the DEN is the framework binding the various simulators and third-party networks together, controlling the flow of information and making it easily accessible to those who need it most.



Typhoon FGR4
The RAF's primary multi-role combat aircraft, the Typhoon can be deployed in a wide range of offensive and defensive operations. One of the most advanced fighter jets, it's capable of hitting Mach 1.8.

Type 45 destroyer
Britain's most advanced warship, the Type 45 is an anti-aircraft beast, capable of shooting down hostile planes with a huge arsenal of missiles and guns.



E-3D Sentry AEW1
The E-3D Sentry is an airborne surveillance and command-and-control aircraft that specialises in reconnaissance and target acquisition.

F-35 Lightning II
While currently not supported by DEN, over the next 18 months BAE is hoping to integrate support for the F-35, the fighter jet set to become the showpiece of the RAF's military fleet in the next 20 years.

A virtual rival

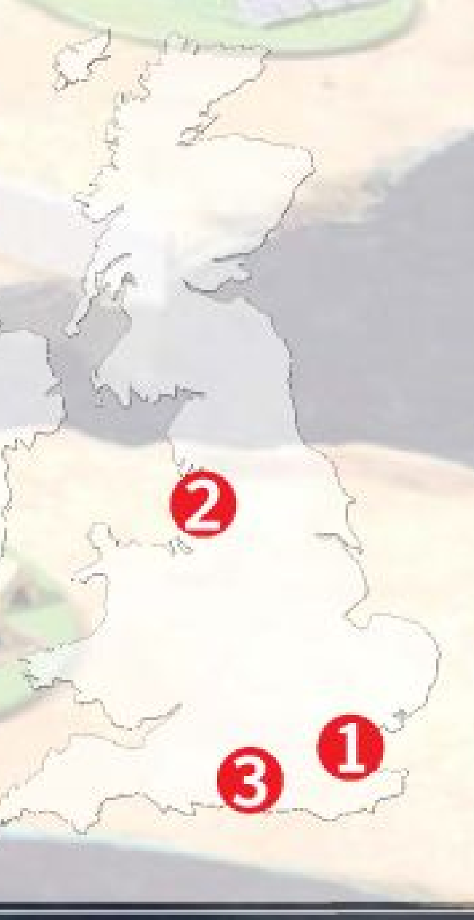
Facing up against BAE Systems' DEN in the battle for virtual combat training supremacy is American defence contractor Lockheed Martin's Multi-Function Training Aid (MFTA). The MFTA is pitched as being a reconfigurable platform for a wide range of military vehicles, with the system capable of simulating fixed-wing multi-crew aircraft, helicopters, landing hovercrafts, fast attack boats, trucks and even utility vehicles.

The system is based on Lockheed's own Prepar3D simulation software, with a comprehensive suite of simulated controls, multitouch glass panels and authentic cockpit layouts (pictured below) allowing the user to adapt quickly to their specific training vehicle. Data for the system comes courtesy of the WGS-84 database, allowing things like traffic, weather and other factors to be realistically replicated. Throw in extras like a built-in motion platform, electro-optical, infrared and radar sensors as well as real heads-up displays and it's obvious that the MFTA offers new soldiers a valuable insight into life on the battlefield.

❶ New Malden facility
The E-3D Sentry is simulated on its own at BAE's New Malden site, linked to the simulated environment by BAE's DEN.

❷ Warton facility
Four virtual Typhoons are simulated from BAE's facility in Lancashire and link in to the battle system.

❸ Broad Oak facility
The simulator for the system's Type 45 destroyer is located at BAE's Broad Oak facility, near the famous Portsmouth dockyard.



© BAE Systems; Lockheed Martin

What does a panic room comprise of?

What goes into the ultimate home defence unit?

Panic rooms rose to fame in 2002 when Jodie Foster starred in a film where they were trapped in one, but what are these modern-day boltholes and how are they constructed?

A panic room is a safe place for occupants of a property to go whenever they feel threatened. The danger could be in the form of an intruder or a natural threat like an earthquake or hurricane. These rooms are typically windowless for maximum security and the only weak point of these rooms might be the door, but to combat this, panic room doors are constructed from super-thick steel, have reinforced frames and are fitted with high-level security locks. Fingerprint scanners or keycode entry pads provide an extra barrier, and sometimes the door is so well concealed that a trespasser may not even know the room exists.

The room must provide all the essentials for staying alive during a potential long-term situation, so basic plumbing, air filtration and a good stock of medical kit, food and water are all standard. The most expensive panic rooms might also feature monitors hooked up to a CCTV system in order to keep an eye on intruders' movements as well as a means of communication to contact the outside world - and avoid the scenario in the 2002 film.

Thankfully, most panic rooms aren't as tension-filled as 2002's Panic Room

A game of hide and seek

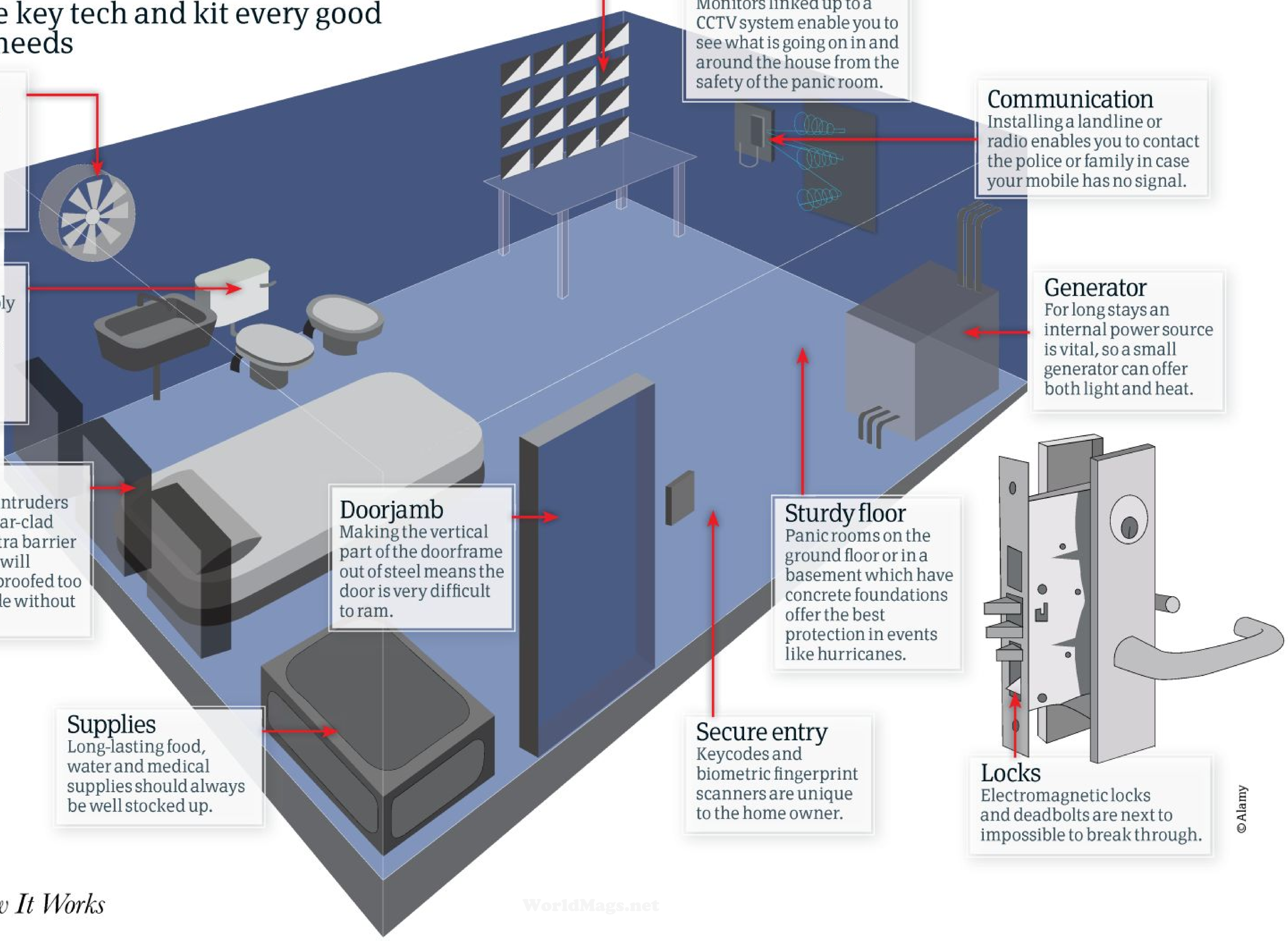
People who are designing custom-built panic rooms to evade intruders are constantly coming up with new and more ingenious ways of keeping these hideaways, well, hidden.

While secret rooms behind bookcases may seem more in line with Enid Blyton fiction than real life, the fact is that a hidden entrance to a panic room could prevent assailants even knowing you're in the building, making it the ultimate defence.

There are examples of panic room doors hidden behind sliding walls, underneath floorboards or through the back of a closet. To ensure a panic room is as well hidden as possible, companies are offering tailor-made services, creating precisely constructed moving walls, which can barely be seen without prior knowledge. Although these are very costly, the peace of mind that comes with increased safety often takes precedence.

Panic room essentials

Explore the key tech and kit every good safe room needs



Surveillance Monitors linked up to a CCTV system enable you to see what is going on in and around the house from the safety of the panic room.

Air filtration If you're going to be in an enclosed environment for a while, a system for circulating fresh air is a must.

Communication Installing a landline or radio enables you to contact the police or family in case your mobile has no signal.

Plumbing Nature will inevitably call if stuck in the room for some time, so a toilet is a must and a sink provides essential water.

Generator For long stays an internal power source is vital, so a small generator can offer both light and heat.

Kevlar walls If there's a risk that intruders may be armed, Kevlar-clad walls provide an extra barrier of protection. Walls will generally be soundproofed too so you can talk inside without being detected.

Doorjamb Making the vertical part of the doorframe out of steel means the door is very difficult to ram.

Sturdy floor Panic rooms on the ground floor or in a basement which have concrete foundations offer the best protection in events like hurricanes.

Supplies Long-lasting food, water and medical supplies should always be well stocked up.

Secure entry Keycodes and biometric fingerprint scanners are unique to the home owner.

Locks Electromagnetic locks and deadbolts are next to impossible to break through.

© Alamy

Are non-lethal weapons effective?

Cover your ears and discover how sound can be used to stop riots and brawls

To disperse crowds and prevent rioting, various forms of non-lethal weapons (NLW) are used. Among these, interestingly, is sound. Known as an acoustic or sonic weapon, infrasound (super-low frequency) and ultrasound (super-high frequency) greatly affect a human's ears. They can disorientate a target and have psychological effects as well as the physical effects of nausea and damage to the blood vessels.

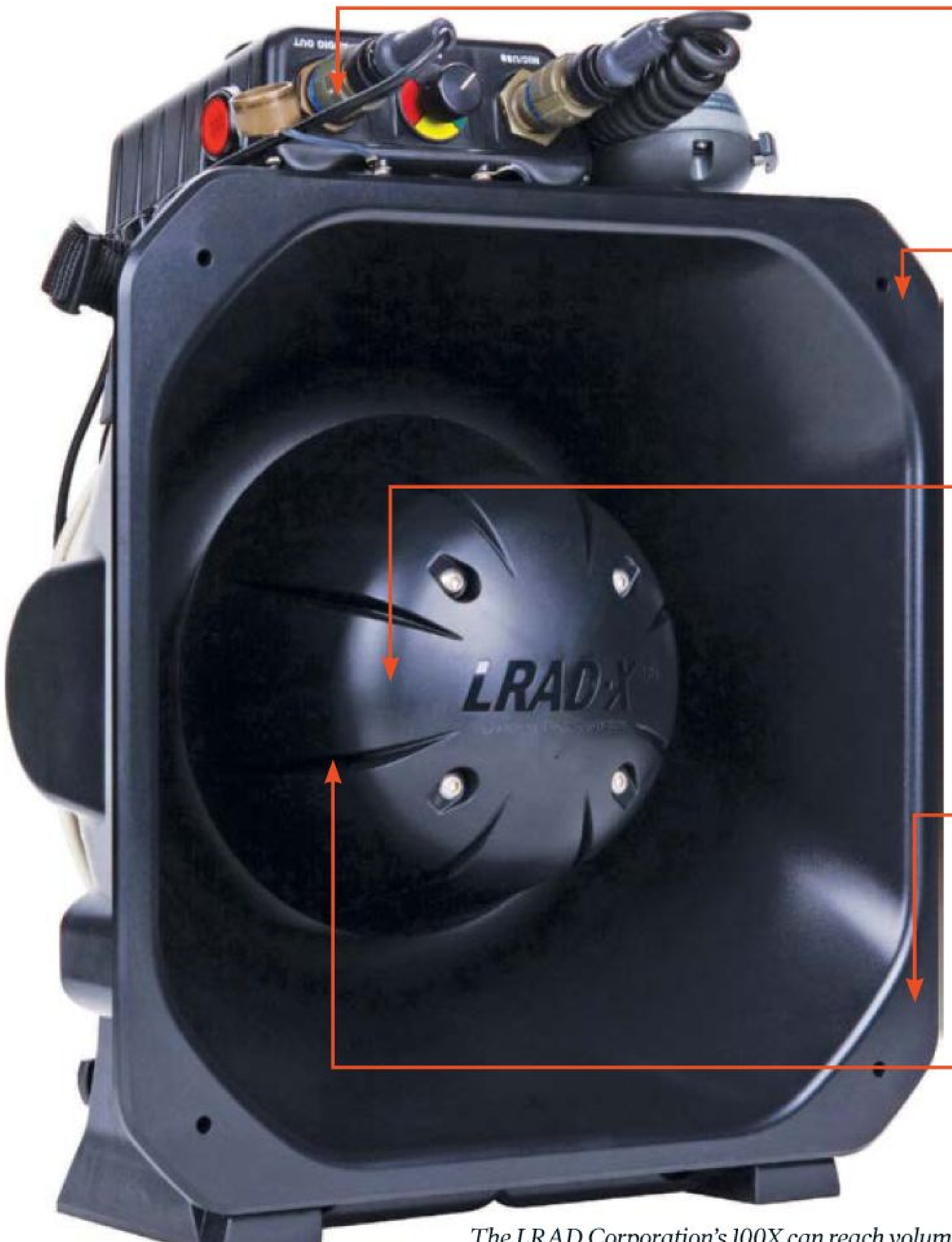
Ultrasound can be increased to 120 decibels (the same volume as a jumbo jet taking off), which is considered the human pain threshold. In contrast, infrasound feels like a damaging vibration or pressure wave, as it's at a frequency too low for humans to hear. When exposed to high levels of sound, the influx of energy has a painful effect on the body.

As well as huge decibels of volume, the variations in frequency can also cause damage. For instance, an infrasound of seven or eight Hertz can rupture blood vessels. Certain types of sound within the frequencies we are able to hear also have psychological effects, acting a sort of musak that can calm people and helps prevent drunken brawls.

In New York City, piezoelectric loudspeakers are used by the NYPD. They focus sound waves in a particular direction to control large crowds. Known as Long Range Acoustic Devices (LRAD), some types can reach a maximum of 162dB. Another device is the sonic bullet. Made by inventor Woody Norris, it sends a beam of up to 145dB into its target. Prototypes are already in production to be used in the US Army to help enforce safety areas in warzones.

Long Range Acoustic Devices

Discover how this breakthrough device uses sound to its advantage



Output
The LRAD 100X is powered by a standard AC source or a rechargeable lithium battery. Its volume can reach up to 137dB.

Portability
Weighing in at a paltry 6.8kg (15lb), the 100X can easily be taken from location to location.

Range
Four to six times louder than all other systems of its size, the 100X has a range of over 600m (1,969ft) and can overcome background noise at 250m (820ft).

Materials
The 100X is made from water- and impact-resistant plastic and aluminium so it is tough enough to withstand riots and combat.

Uses
The system can be used for a variety of situations including law enforcement, border security, communication and even wildlife control.

The LRAD Corporation's 100X can reach volumes of 137dB while the 1000X can reach a hefty 153dB

Perfect match

Match the animal with the power of their sound (measured in decibels)

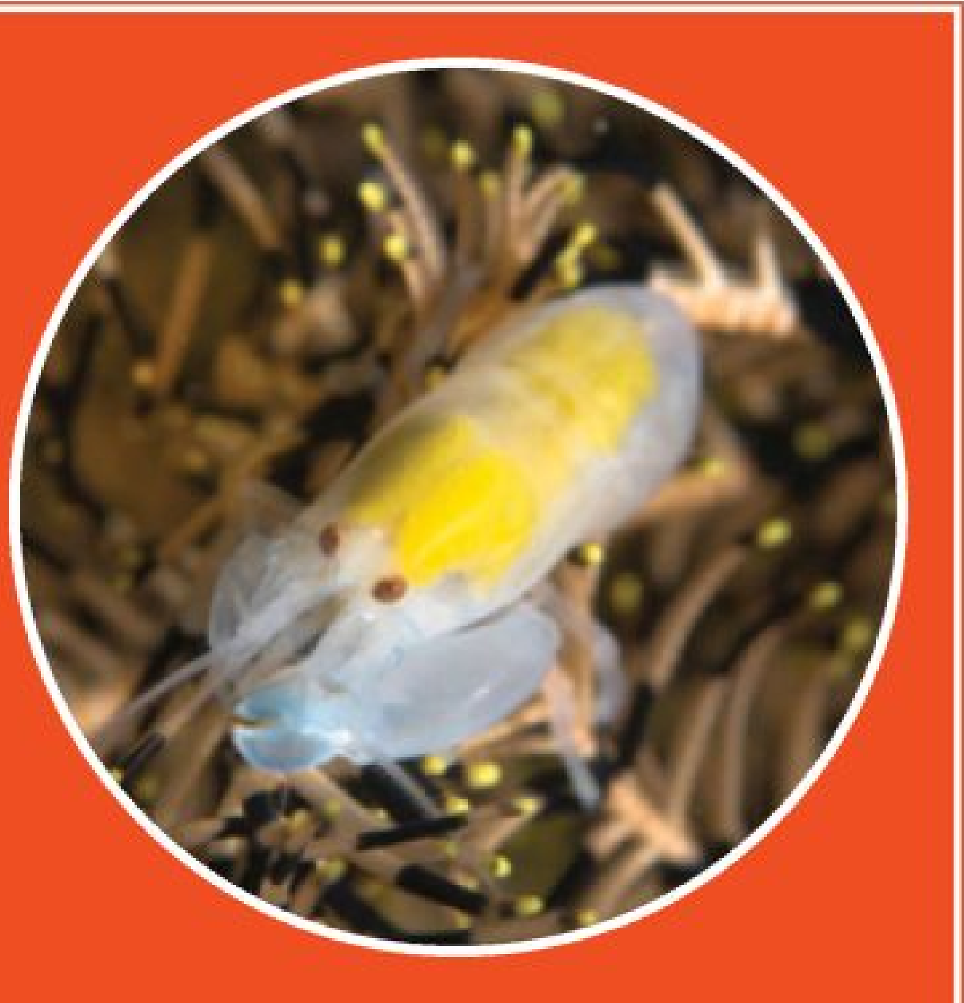
218dB

110dB

230dB

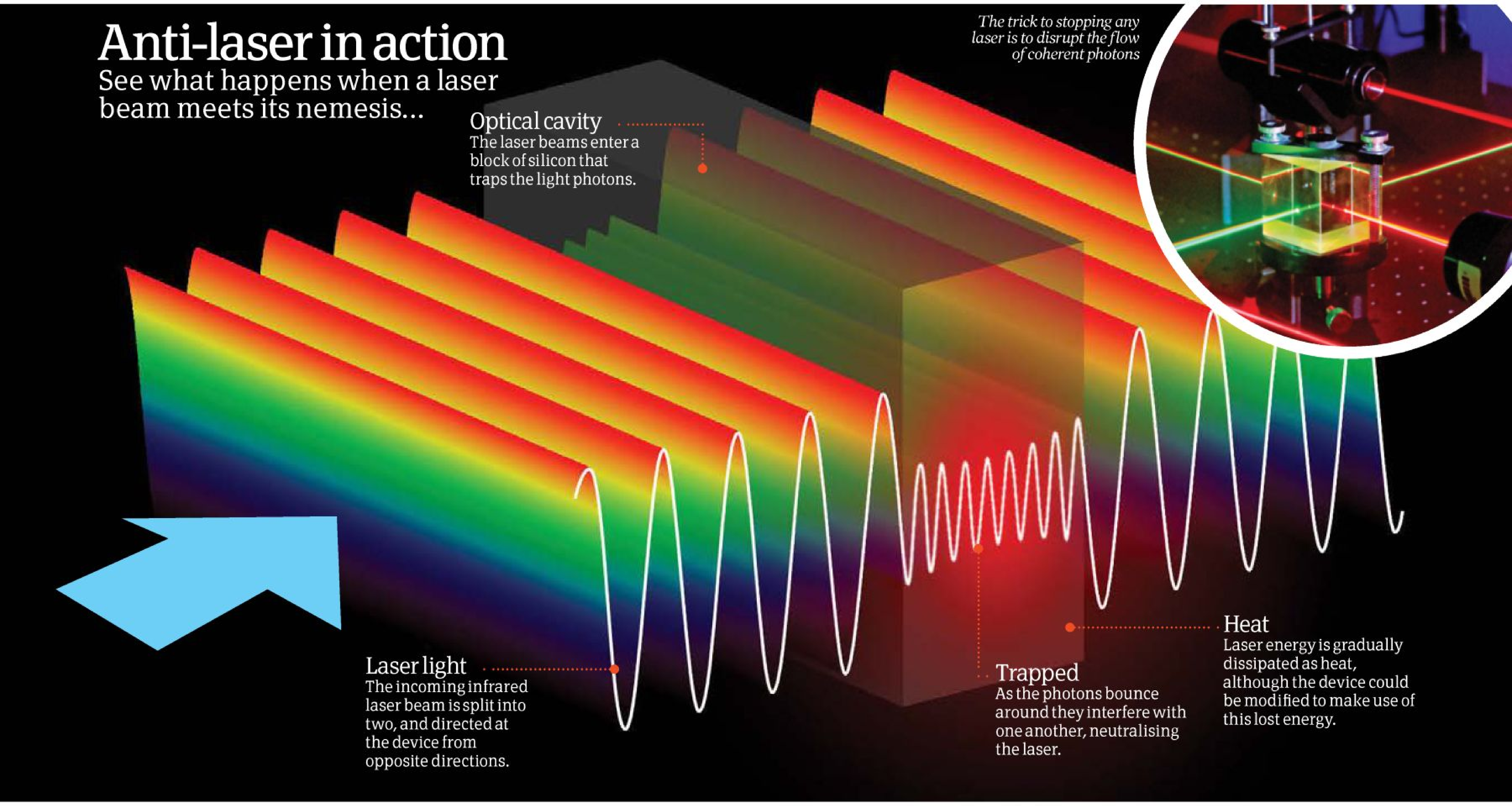
Lion

Sperm whale


Tiger pistol shrimp

Answers: 218dB = tiger pistol shrimp; 110dB = lion; 230dB = sperm whale

© LRAD Corporation; Thinkstock; Alamy



Anti-laser in action

See what happens when a laser beam meets its nemesis…

The trick to stopping any laser is to disrupt the flow of coherent photons

Optical cavity
The laser beams enter a block of silicon that traps the light photons.

Laser light
The incoming infrared laser beam is split into two, and directed at the device from opposite directions.

Trapped
As the photons bounce around they interfere with one another, neutralising the laser.

Heat
Laser energy is gradually dissipated as heat, although the device could be modified to make use of this lost energy.

What is inside an anti-laser?

The tiny device that can stop a laser in its tracks

Faced with the puzzle of creating a device that could absorb laser energy, researchers at Yale looked at how laser light is produced and simply reversed the process. What they created in 2011 was the first anti-laser, or coherent perfect absorber (CPA).

Conventional lasers work by stimulating atoms in what's called a gain material. As these excited atoms drop back down to a less excited state, they emit photons with the same wavelength, creating light waves that are in step. Inside the laser amplification cavity, mirrors bounce these photons back and forth, causing excited atoms to emit photons of exactly the same wavelength. The result is a huge number of photons with the same frequency and direction, creating a focused beam of intense light energy.

The anti-laser demonstrated by Yale took this basic setup and switched it around. First a laser beam is split into two, with one of the two resulting beams being modified so it is out of step with its counterpart. The two incoming laser beams are directed at a small slab of silicon. The surface of the silicon acts as a one-way trapdoor, allowing the light to enter but not escape. As the two beams bounce around inside the silicon, they gradually lose energy as they cancel each other out through interference. Although the existing prototype can absorb 99.4 per cent of light, in theory it could be optimised to absorb 99.99 per cent.

More generally, the idea of reversing the process of laser light production by different materials could be used to investigate how those materials absorb light.

Developing anti-lasers

We asked A. Douglas Stone, professor of Applied Physics at Yale University, for his take on the anti-laser technology he developed

What's so special about an anti-laser?

ADS: We realised that the strength of the anti-laser was that if you hit an opaque medium with exactly the right pattern of light then it would penetrate the medium and be absorbed. This is a totally new principle.

What applications does this have?

ADS: Suppose I want to know what's happening inside a solar cell. Depending on where in the cell the light is absorbed, the cell's efficiency at collecting energy varies. We can focus light deep within the cell to see how that changes things. If you're trying to perfect solar cells it's very exciting, although it might not resonate with the public just yet!

So there aren't any direct defence applications for anti-lasers?

ADS: When our research was published a lot of people thought it was somehow a defence against laser [weapons]. A mirror is a better defence – it's easier to get a laser to bounce off something than to absorb it. We've developed a selective absorption technique.

© Yidong Chong/Yale University; Alamy

Can you use the Sun to cook?

How we can harness the Sun to get our sausages sizzling

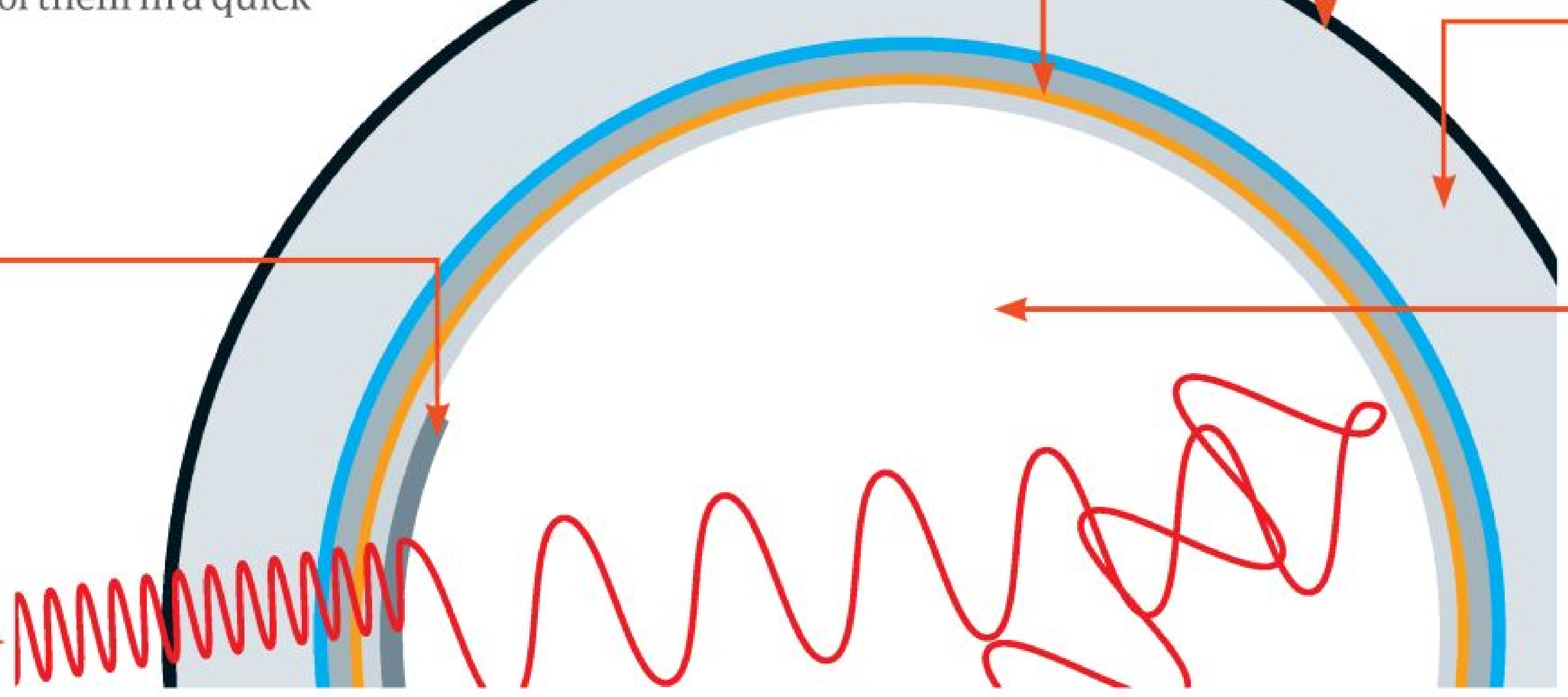
A new stove has been invented that uses an evacuated tube to cook food using solar energy. The evacuated tube on the GoSun Stove consists of two heat-resistant borosilicate glass cylinders, which create a vacuum seal when the cooking tray is inserted. Around the inner cylinder is an aluminium nitrile ring that catches and absorbs sunlight and a copper ring that prevents infrared radiation from escaping. This aluminium nitrile draws over 80 per cent of sunlight in and the copper keeps it there even after the Sun has set.

The highly reflective aluminium housing makes the system even more efficient. When fully opened, the curved surface deflects light onto the evacuated tube.

The chef loads up the stainless-steel semicircular tray with food and slots it into the 0.6-metre (two-foot)-long tube, which the inventors say should be big enough to hold 12 standard hot dogs and can cook four of them in a quick ten minutes.

Inside the GoSun

How does this fuel-free stove cook food so efficiently?



Copper ring The ring of copper stops infrared radiation from escaping, keeping the heat in the tube.

Outer cylinder The borosilicate glass lets light through and is resistant to cracking when rapidly heated.

Aluminium nitrile This layer of material absorbs the light, drawing it into the tube.

Food tray The food tray is made out of a stainless steel, which heats up and cooks the food from underneath.

Inner tube When the food tray is inserted, the two glass tubes create a vacuum seal that insulates the system.

Solar radiation

What's a Sharkstopper?

An amazing tech to prevent shark attacks

An ankle bracelet has been developed for swimmers/surfers that uses whale noises to ward off sharks. Sharkstopper emits the call of killer whales on specific frequencies of less than 500 hertz, which sharks are very responsive to. The call scares the sharks away as killer whales are one of two creatures in the world that are known to hunt and kill sharks, the other being humans.

This audio assault keeps swimmers safe but doesn't harm the shark or the wearer in any way. It can also be used on buoys to keep sharks away from a particular area or fishing boats to stop them getting tangled in nets. The ten-centimetre (four-inch)-long device weighs the same as a smartphone and uses a water-activated sensor to start emitting sounds. The battery lasts for seven hours and vibrates when it needs to be recharged via USB. Sharkstopper has already been proven to repel hammerhead, bull, tiger and great white sharks among others.

The Sharkstopper sends out whale sounds on a specially tested frequency to repel sharks

© REX Features; Solent News; SharkStopper

How was the Empire State Building built?

How this US icon came to tower over New York City

With 103 floors and a 56-metre (185-foot) spire, the Empire State Building is an incredible 443.2 metres (1,454 feet) high. The world's tallest skyscraper when it was opened on 1 May 1931, it pipped New York's beautiful 319-metre (1,046-foot) Chrysler Building to the record and held onto it until 1970, when New York City saw the World Trade Centre spring from the pavement. They certainly build them big in the Big Apple and for 40 years, the Empire State Building was the biggest of them all.

The invention of steel framing in the late-19th century had made it possible for buildings to be taller than ever. While brick would eventually collapse under its own weight if you piled on too many floors, a honeycomb-like frame of steel beams could take the strain and spread the pressure of the upper floors throughout the building. Another 19th-century development – the elevator – raised the limit on how many storeys you could put on a building, for the reason that you can't expect someone to climb 102 flights of stairs.

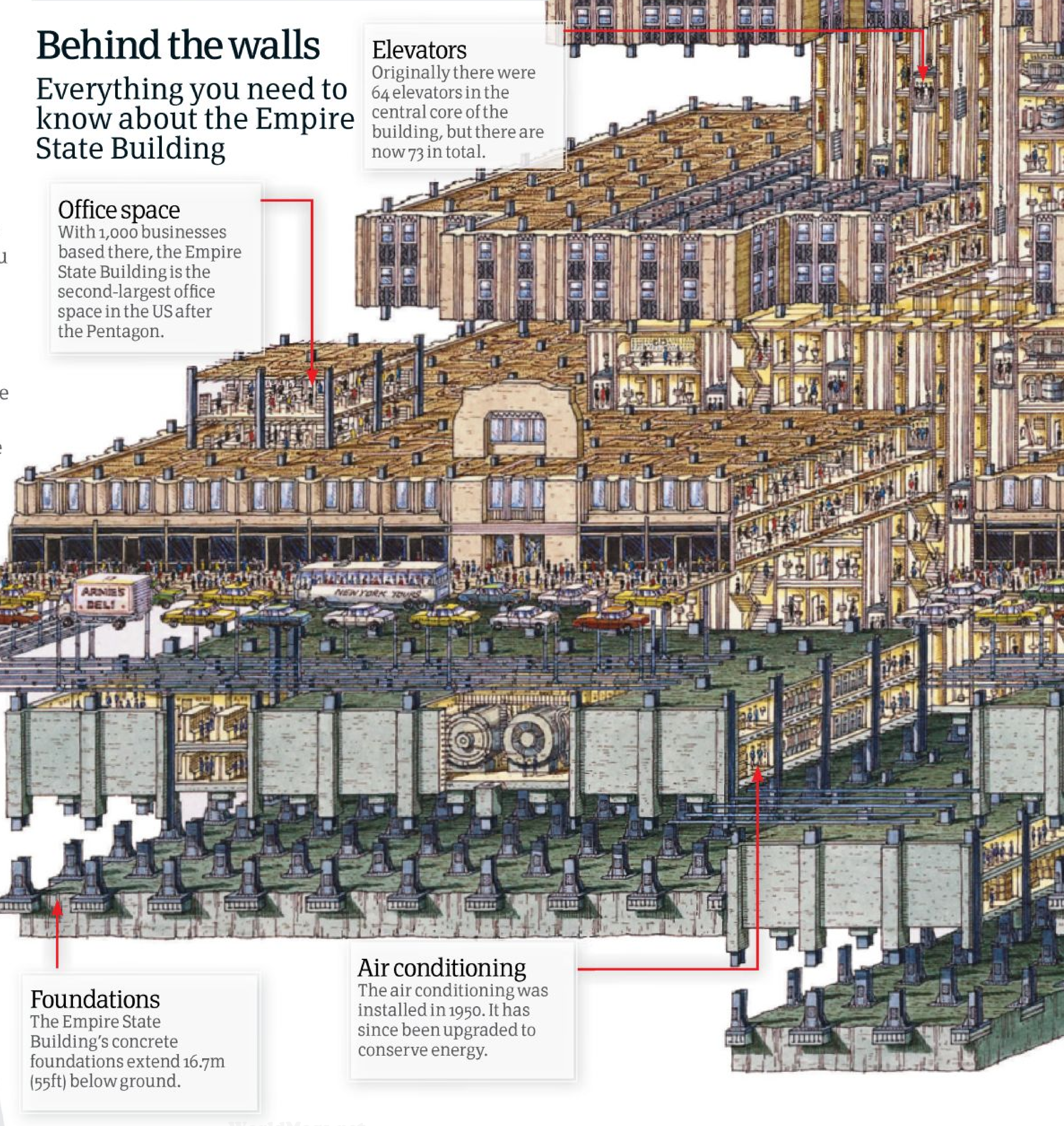
Construction began in March 1930. Financed by two former General Motors executives, John J Raskob and Pierre S du Pont, they applied the same revolutionary style of working that they'd used in the factory, with assembly lines of men putting the building together in shifts. However, without the benefit of modern cranes and lifting equipment, materials were hoisted up by pulleys and moved around the inside of the building on narrow railway tracks.

As many as 3,500 workers were on the building at once, many of them (known as 'sky boys') balancing on beams high above the city with no harnesses or helmets. It would be considered incredibly dangerous and reckless today, but those conditions were accepted as part of the job in 1930. Only five people died in the 410 days of its construction.

The 'sky boys' put their lives on the line

Behind the walls

Everything you need to know about the Empire State Building



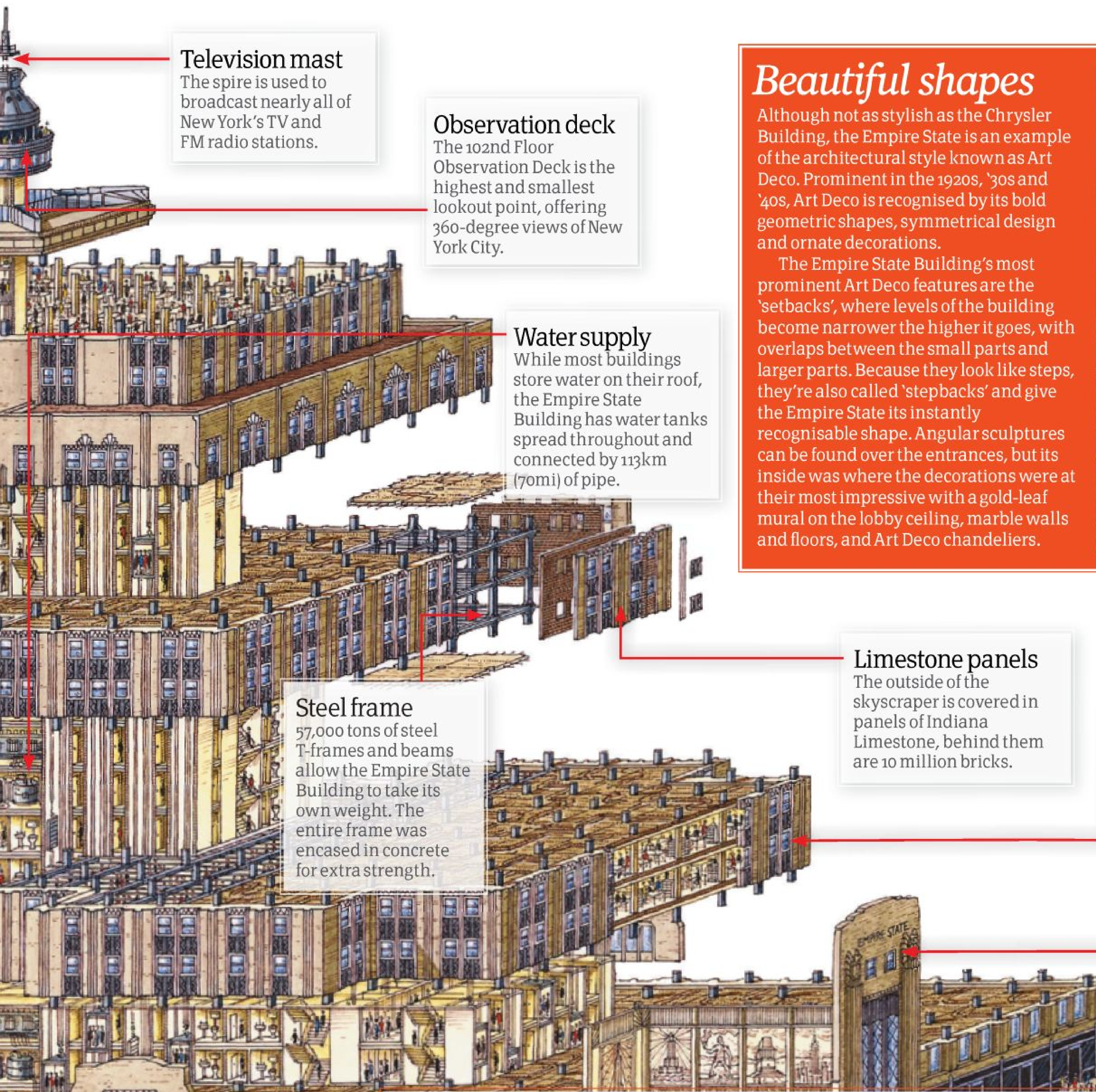
Elevators
Originally there were 64 elevators in the central core of the building, but there are now 73 in total.

Office space
With 1,000 businesses based there, the Empire State Building is the second-largest office space in the US after the Pentagon.

Foundations
The Empire State Building's concrete foundations extend 16.7m (55ft) below ground.

Air conditioning
The air conditioning was installed in 1950. It has since been upgraded to conserve energy.

The Empire State Building is one of New York's most easily spotted landmarks



Television mast
The spire is used to broadcast nearly all of New York's TV and FM radio stations.

Observation deck
The 102nd Floor Observation Deck is the highest and smallest lookout point, offering 360-degree views of New York City.

Water supply
While most buildings store water on their roof, the Empire State Building has water tanks spread throughout and connected by 113km (70mi) of pipe.

Limestone panels
The outside of the skyscraper is covered in panels of Indiana Limestone, behind them are 10 million bricks.

Steel frame
57,000 tons of steel T-frames and beams allow the Empire State Building to take its own weight. The entire frame was encased in concrete for extra strength.

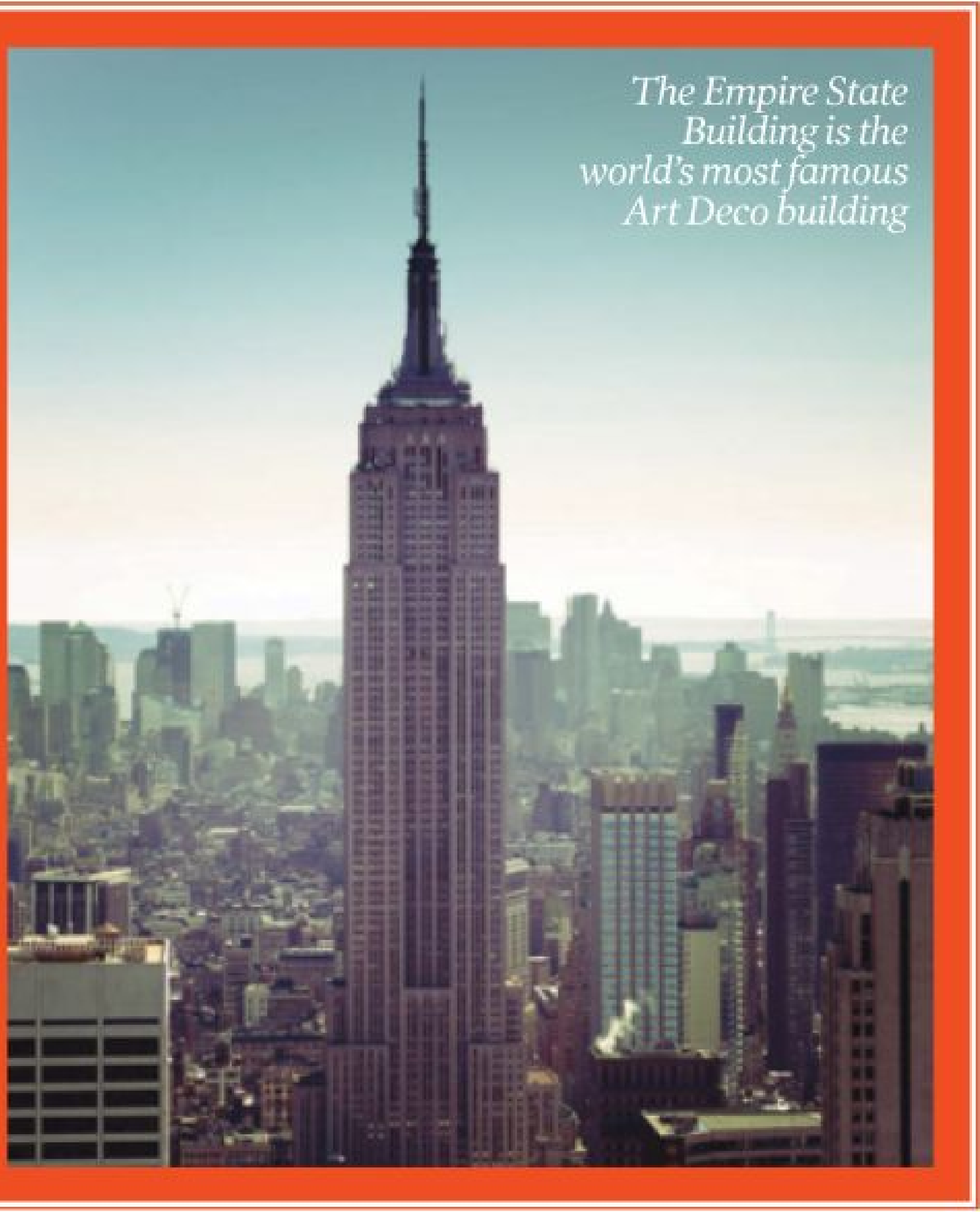
Windows
Did you know there are 6,500 windows in the Empire State Building? That's a lot of cleaning!

Entrance
The main entrance has a 9.1m (30ft) high frontage with diamond-shaped frames of glass and two carved eagles on pillars.

Beautiful shapes

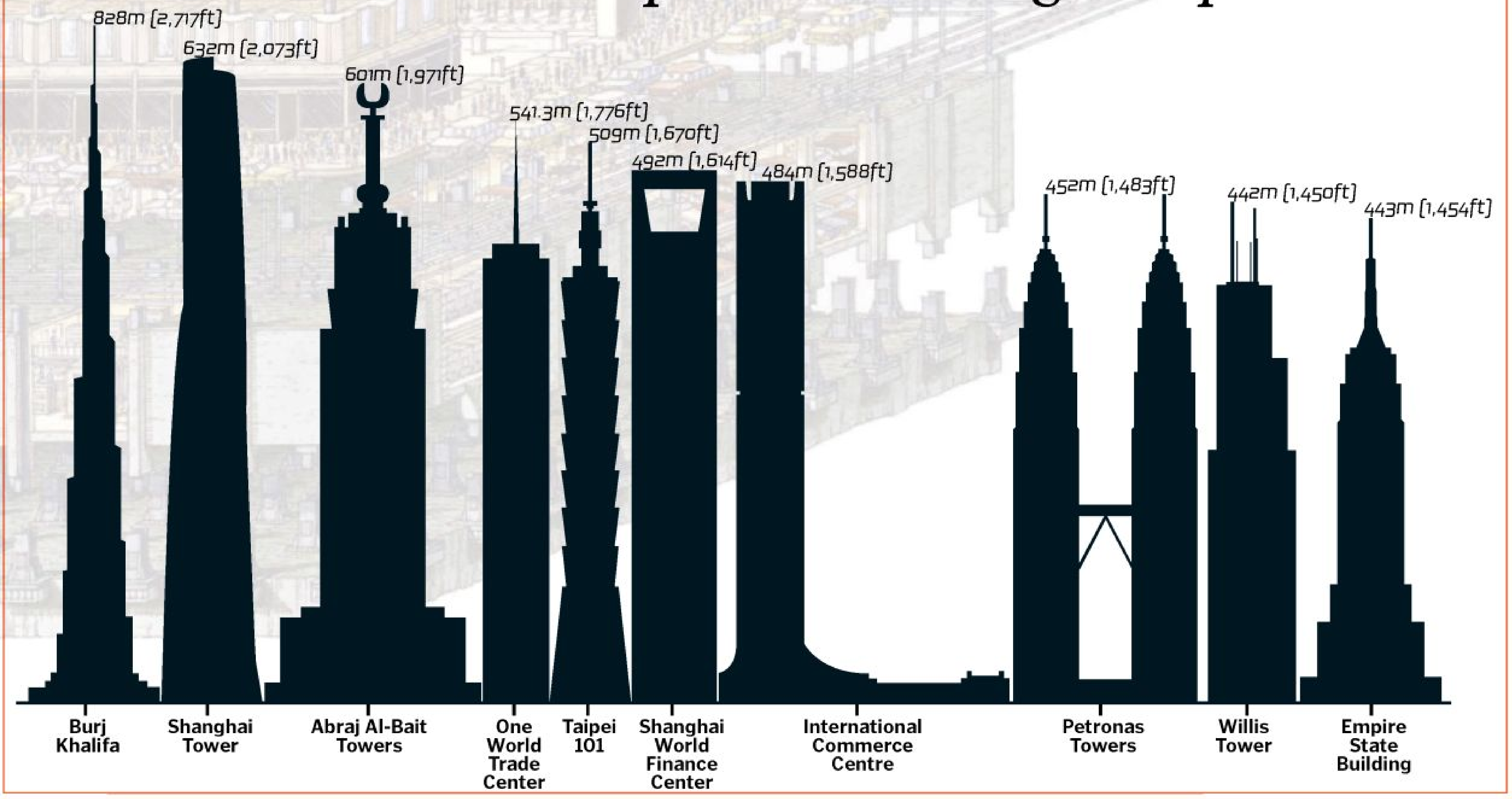
Although not as stylish as the Chrysler Building, the Empire State is an example of the architectural style known as Art Deco. Prominent in the 1920s, '30s and '40s, Art Deco is recognised by its bold geometric shapes, symmetrical design and ornate decorations.

The Empire State Building's most prominent Art Deco features are the 'setbacks', where levels of the building become narrower the higher it goes, with overlaps between the small parts and larger parts. Because they look like steps, they're also called 'stepbacks' and give the Empire State its instantly recognisable shape. Angular sculptures can be found over the entrances, but its inside was where the decorations were at their most impressive with a gold-leaf mural on the lobby ceiling, marble walls and floors, and Art Deco chandeliers.



The Empire State Building is the world's most famous Art Deco building

How does the Empire State Building size up?



© Thinkstock; DK

What is inside a computer mouse?

How did one little invention help us point and click?

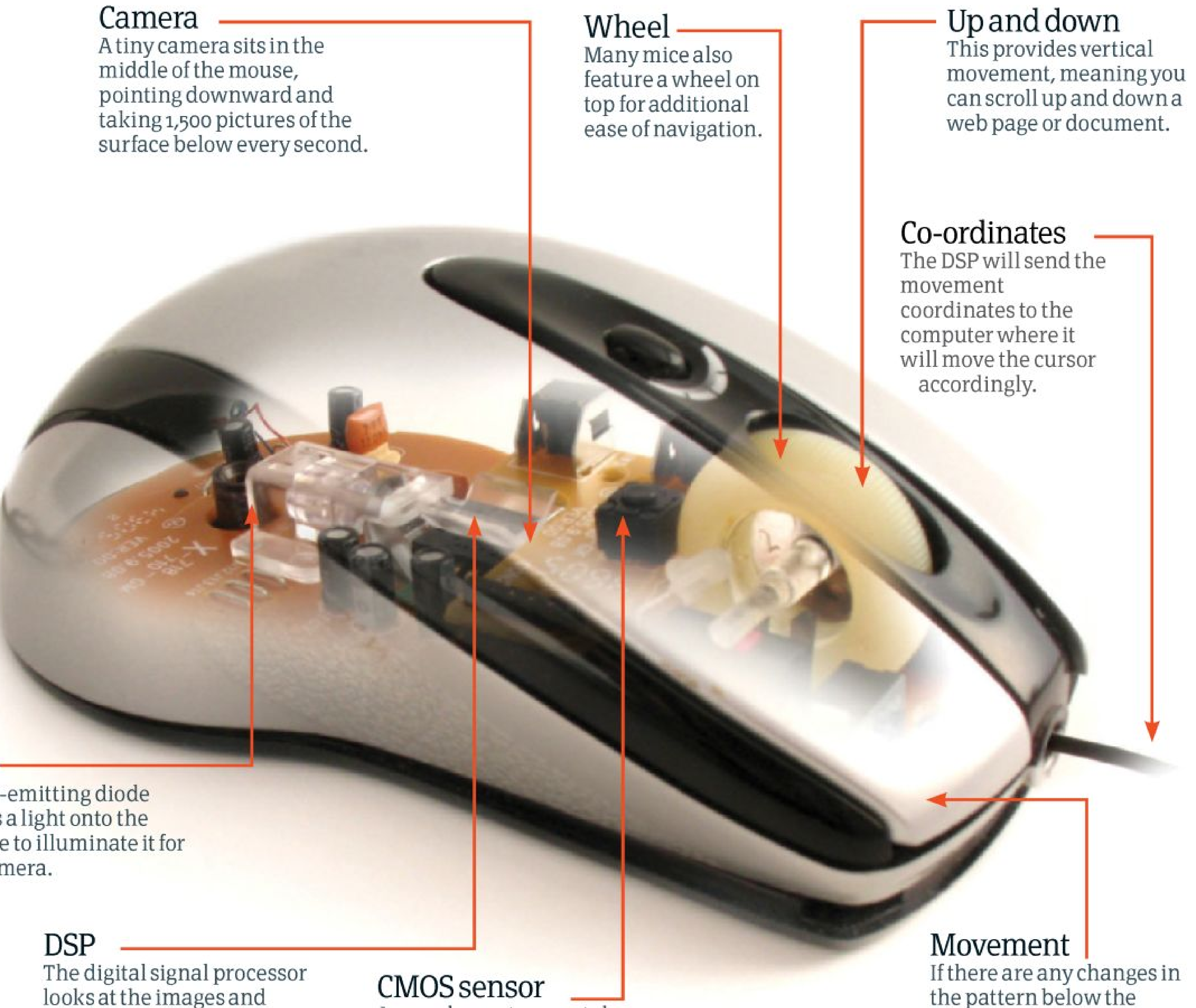
Chances are if you are using a mouse to navigate around your computer that it's an optical mouse. It was invented in 1980 and has pretty much completely replaced the ball-guided mouse. An optical mouse works using microscopic imaging technology. First, a tiny camera inside the mouse photographs your desk or mousemat. The red glow you can see if you turn it upside down is a red light-emitting diode (LED) inside that projects light onto the surface. When the light hits the surface and bounces back into the mouse it hits a complementary metal-oxide semiconductor (CMOS). This sends a message to a digital signal processor (DSP), which closely analyses changes in the pattern of the surface. Once it registers a movement, it sends a signal to the computer, which translates that information into a cursor movement. These adjustments happen hundreds of times every second, so it follows your hand movements in extreme detail.

On top of the mouse is usually either a wheel or a tiny rubber ball. These use the same technology as early ball-guided mice. Rotating the wheel or ball with your finger moves a couple of rollers. These are wired up to a processor which analyses how much each roller has moved and allows you to move a web page or document up and down or, with the ball-topped mouse, side to side.

These technological developments have greatly helped day-to-day computing, making navigating around the screen much easier than before and revolutionising PC gaming by enabling precise millimetre-perfect cursor movement.

Inside an optical mouse

What goes on inside your mouse to help you work, rest and play?



Camera
A tiny camera sits in the middle of the mouse, pointing downward and taking 1,500 pictures of the surface below every second.

Wheel
Many mice also feature a wheel on top for additional ease of navigation.

Up and down
This provides vertical movement, meaning you can scroll up and down a web page or document.

Co-ordinates
The DSP will send the movement coordinates to the computer where it will move the cursor accordingly.

LED
A light-emitting diode shines a light onto the surface to illuminate it for the camera.

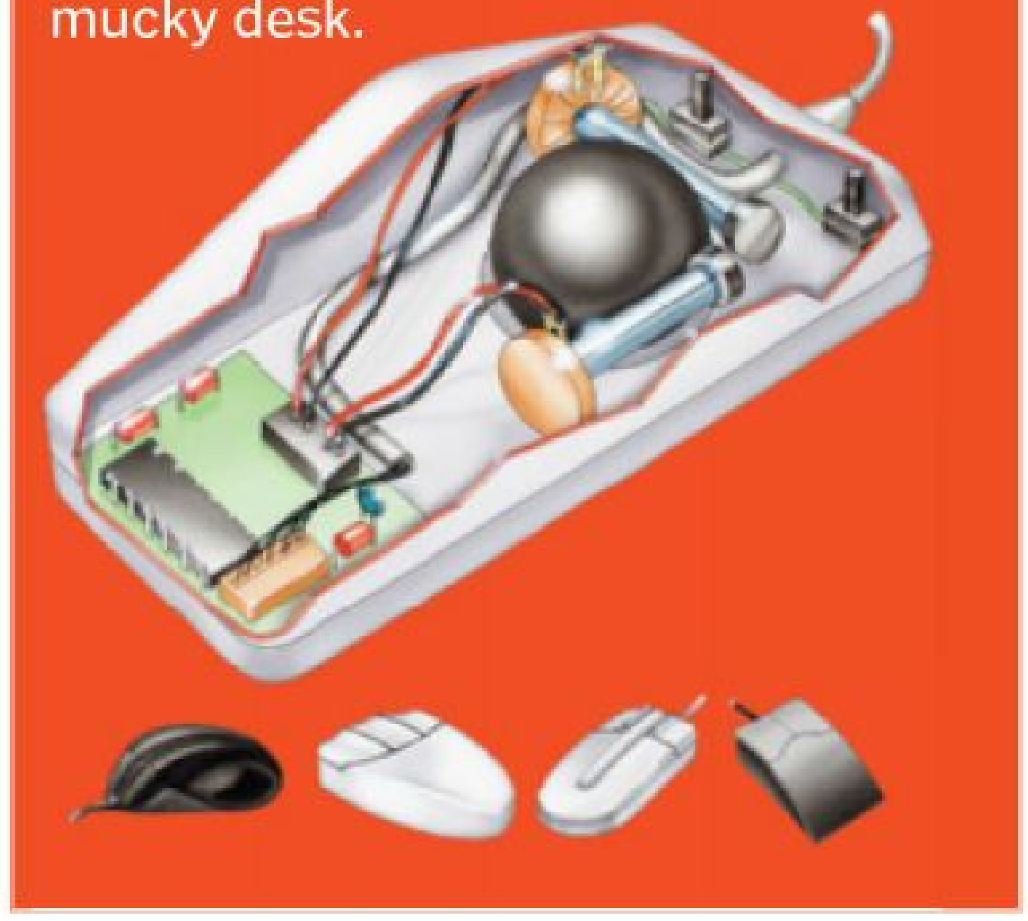
DSP
The digital signal processor looks at the images and notices if there have been any changes in the surface below the mouse.

CMOS sensor
A complementary metal-oxide semiconductor receives the light that has bounced off the surface and sends it for processing.

Movement
If there are any changes in the pattern below the mouse, the sensors will pick that up and work out how much it has moved.

How the roller-ball mouse worked

The roller-ball mouse was the standard design for years before the optical mouse came along, but what went on inside that casing? As you moved your hand around, the ball rolls too. The ball touched two rollers, one behind and one to the side of the ball to detect vertical and horizontal motion respectively. Wires attached the rollers to a circuit board, transmitting movement data. This data was used to move the cursor around the screen with a greater degree of accuracy than the earlier wheeled mouse. The main downside of the roller ball mouse wasn't anything to do with the electronics. Dirt and grime from the surface it was on would collect inside the hole the ball emerged from, making it stick. The new optical mouse does provide a greater degree of accuracy, but its main advantage over the roller ball is that it won't stick if you have a mucky desk.



How do we take photos in the body?

How we capture images from inside the human digestive system

An endoscopy is any operation involving the study of the inner workings of the human body. Traditionally, an instrument called an endoscope is used, but more recently tiny cameras inside capsules we can swallow have been taking their place. Specialising in the inspection of the intestines, oesophagus and stomach, it can examine places the endoscope could never reach. In particular, it studies the three major sections of the small intestine: the duodenum, jejunum and ileum.

About the size of a pound coin, the capsule transmits images to outside data recorders. It moves naturally through the digestive tract and is designed to help diagnose the causes of chronic diarrhoea, inflammatory bowel disease, abdominal pain and malabsorption.

To capture images, the mechanism shines a light from its LED source onto the wall of any part of the gastrointestinal tract. These images are then transported by radio waves to a nearby receiver or monitor for analysis.

If there's a downside, it is that currently the camera can't be stopped to take a closer look at anything, as it's moved by natural peristalsis.

To date, over 400,000 procedures have been performed worldwide and retention has occurred in only 0.75 per cent of cases, so the chances of it not passing through safely are very slim. In around eight hours the capsule can capture an incredible 50,000 or so images.

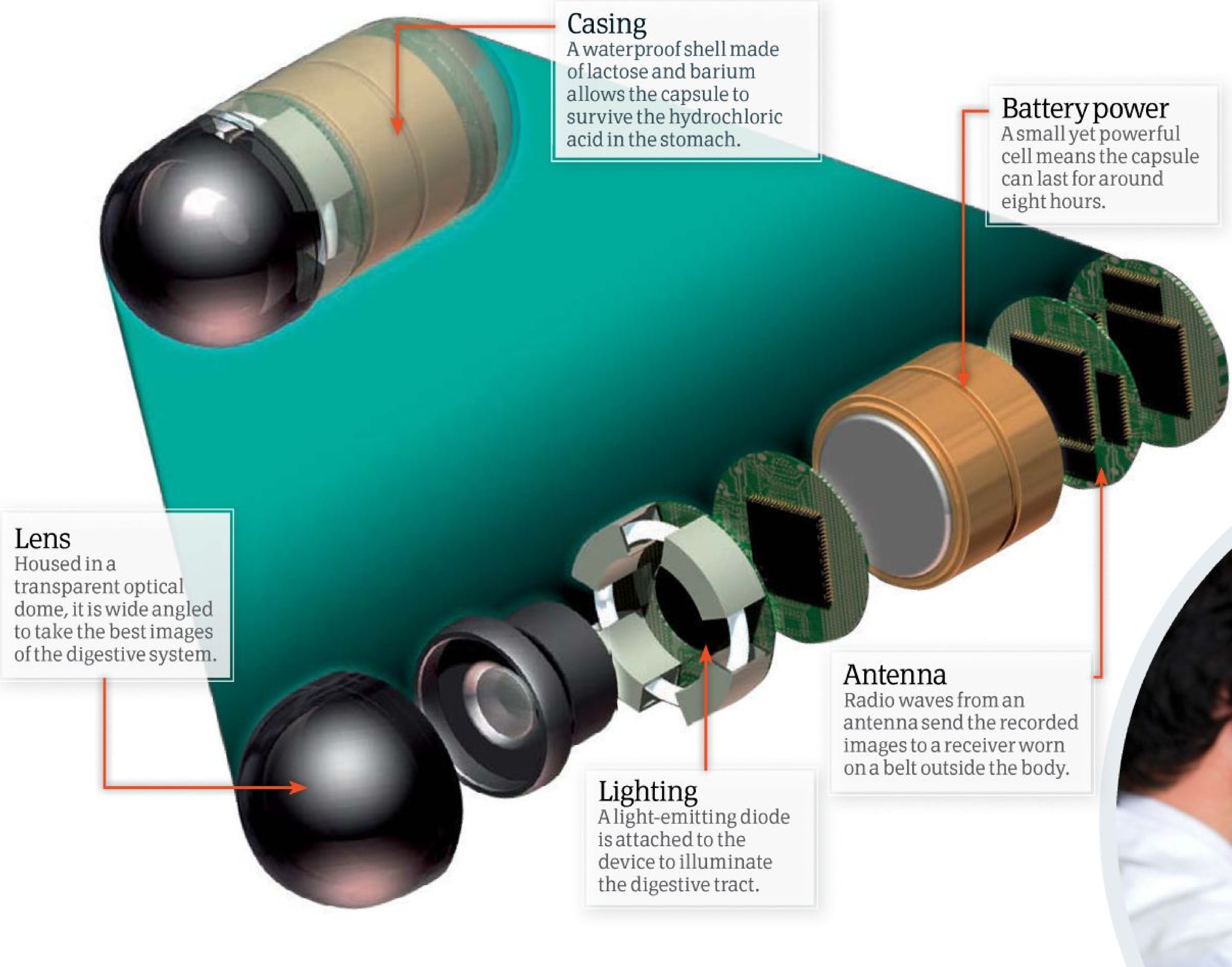
It costs about £600 ($1,000) to administer but its ability to explore parts of the digestive system in unprecedented detail – outside invasive surgery – is invaluable.

Nil by mouth

Camera capsule endoscopy is a painless and relatively fast process. To allow the procedure to work effectively, the patient must observe a few important measures. Prior to examination, the patient must not eat or drink anything for 12 hours. In some cases, patients may also need to cleanse their bowel before the procedure takes place. After taking the capsule, you can move around as long as you don't make any sudden movements. The vast majority who have used the capsule said they felt no pain or discomfort. You can drink clear liquids two hours after ingestion and eat food after four hours.

The camera in a pill

What technology makes up this inner-body explorer?



Casing
A waterproof shell made of lactose and barium allows the capsule to survive the hydrochloric acid in the stomach.

Battery power
A small yet powerful cell means the capsule can last for around eight hours.

Lens
Housed in a transparent optical dome, it is wide angled to take the best images of the digestive system.

Antenna
Radio waves from an antenna send the recorded images to a receiver worn on a belt outside the body.

Lighting
A light-emitting diode is attached to the device to illuminate the digestive tract.

Images can be instantly transmitted to a computer for closer analysis

© Rex Features; Corbis; DK Images

How is a mega-aquarium built?

Dive inside one of the largest aquariums on Earth and discover how we replicate an ocean in a tank

Aquariums, and in particular the awe-inspiring tunnel oceanariums that allow you to walk through marine environments yet stay completely dry, are amazing feats of modern engineering.

First of all, the engineers have to ensure the glass is strong enough to hold back up to 42.8 million litres (11 million gallons) of water. And no, we haven't just plucked that number out of thin air; that's the capacity of the SEA Aquarium in Singapore (see main image).

The SEA's acrylic panel is 36 metres (118 feet) wide, 8.3 metres (27.2 feet) tall and over 70 centimetres (27.6 inches) thick to cope with the immense pressure generated by the huge volume of water. Behind this panel are all manner of marine creatures, from goliath groupers to giant manta rays.

Even after the tanks have been constructed, the water poured in and salinated and the various fish introduced to their respective homes, a lot of upkeep is required to keep the tank in good condition. As the tanks are far more contained than the endless oceans, cleaning up waste matter and uneaten food must take place regularly to keep the inhabitants healthly. This is done using one of three common filtration techniques. Mechanical filtration employs filters and pumps to remove waste, fractionation separates the water from particles that have dissolved in it, and finally there is ozone, which kills off harmful bacteria in the water, much like chlorine in swimming pools.

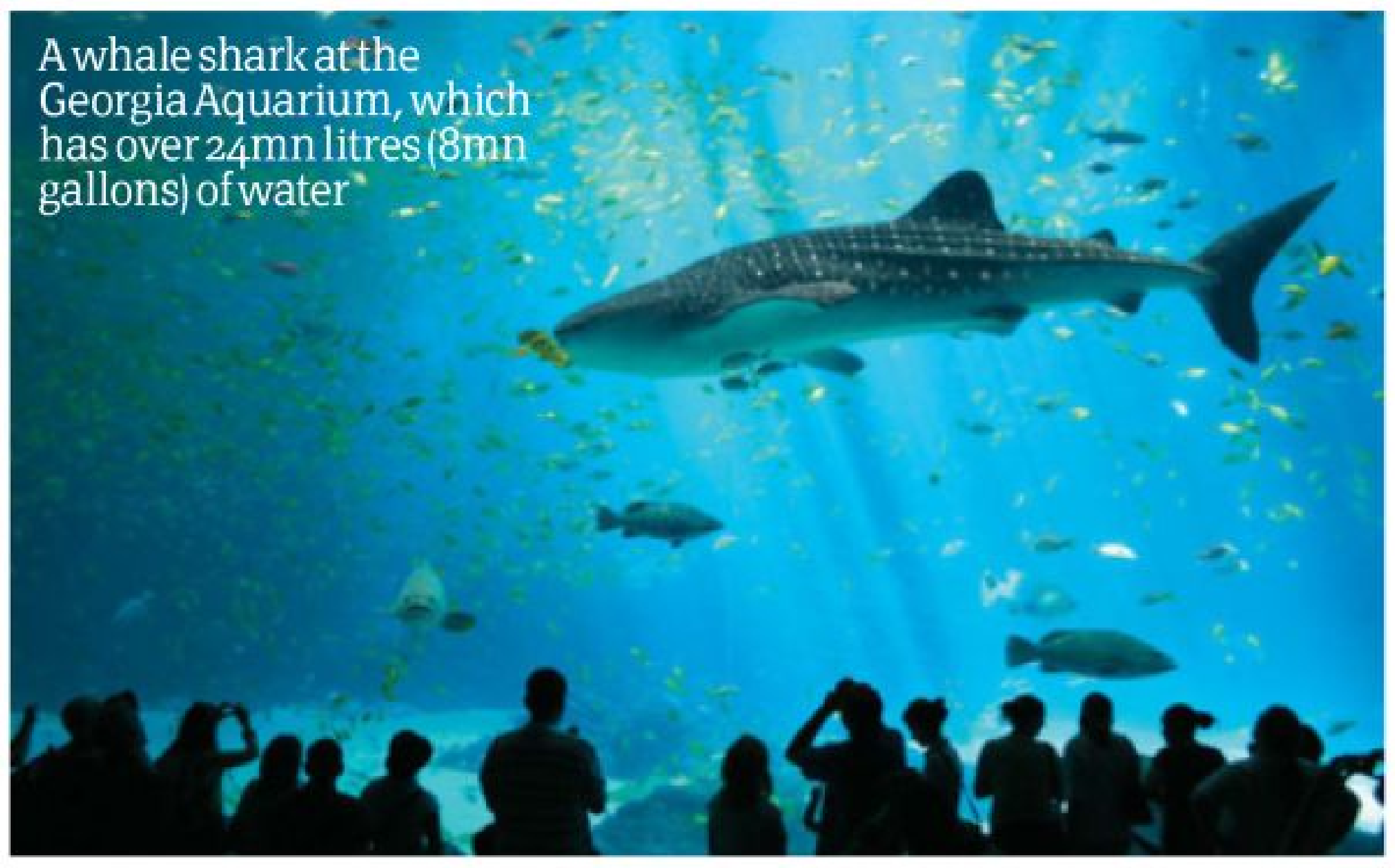
In order to keep the tanks clean for fish and viewers alike, sand filters and skimmers are also incorporated. The sand filters use pumps to blast the water through them and debris is caught by the fine grains, while the protein skimmers pass the water through a valve that injects air into it. This creates lots of tiny little bubbles which any unwanted debris sticks to. ⚙

Clear strength

Aquarium tanks have to meet rigorous safety standards. Often, all that stands between the public and millions of litres of water, sharks and other fish is a single sheet of acrylic. Acrylic has become the standard in aquariums due to its dual qualities of being extremely strong and transparent. The latter quality it, of course, shares with glass, but acrylic's strength really sets it apart.

Acrylic sheets are up to 17 times stronger than glass and have the added advantage of not becoming weakened by prolonged exposure to water. The high molecular weight of cast acrylic sheets makes cutting the panel much easier and the flexible nature of the plastic allows for curved viewing portals without compromising on structural integrity.

Although glass doesn't scratch as easily, acrylic is the way to go for a strong, durable, flexible and transparent material to best show off an aquarium's inhabitants.



A whale shark at the Georgia Aquarium, which has over 24mn litres (8mn gallons) of water

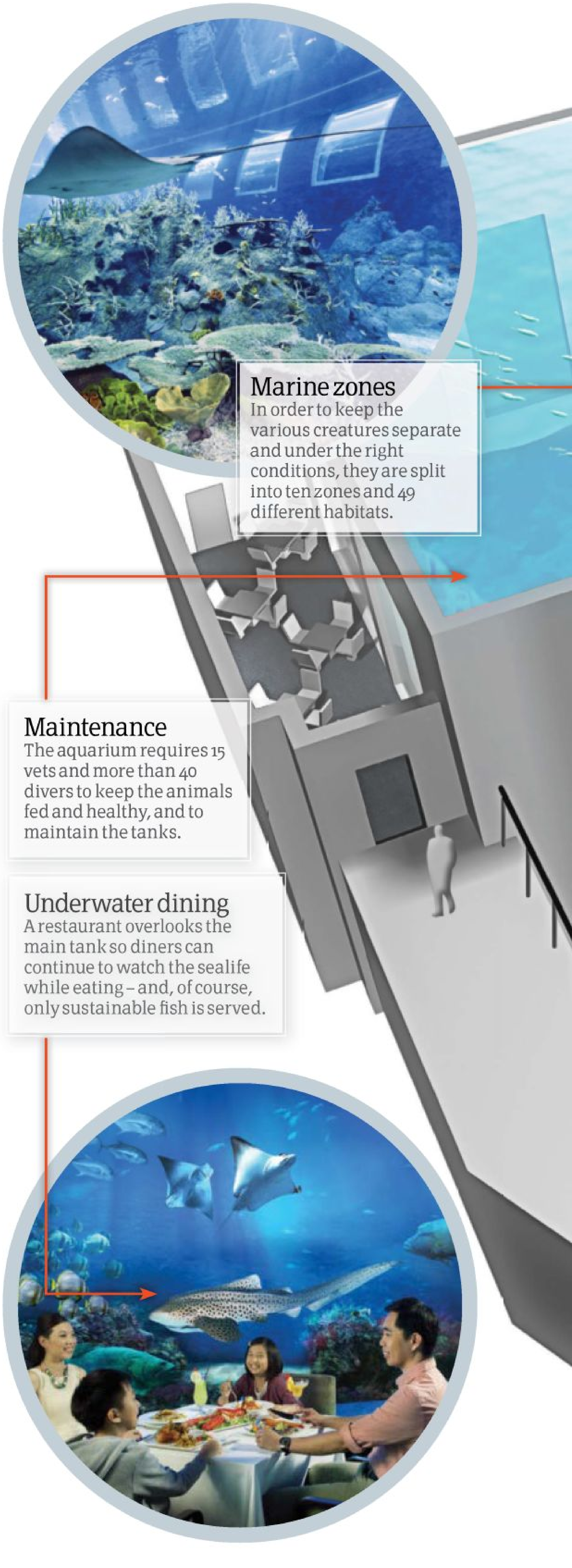
Re-creating marine habitats

Every large aquarium has to deal with the challenge of meeting the needs of the diverse creatures it plays home to. Visitors want to see salt and freshwater fish, plus other creatures, so they have to replicate a variety of environmental conditions. The Ocean Voyager tank in the Georgia Aquarium, USA, poured 680,000 kilograms (1.5 million pounds) of sea salt into its 24-million-litre (6.3-million-gallon) tank. After this initial outlay though, the tank requires very little salt to keep it salinated.

Water temperature is also very important. Depending on the location and inhabitants, temperature varies wildly, so tanks are constantly checked and controlled by thermostats and heaters. For fish that live in deep water, dim lights are used so we can see them without upsetting their natural environment.

Explore the SEA Aquarium

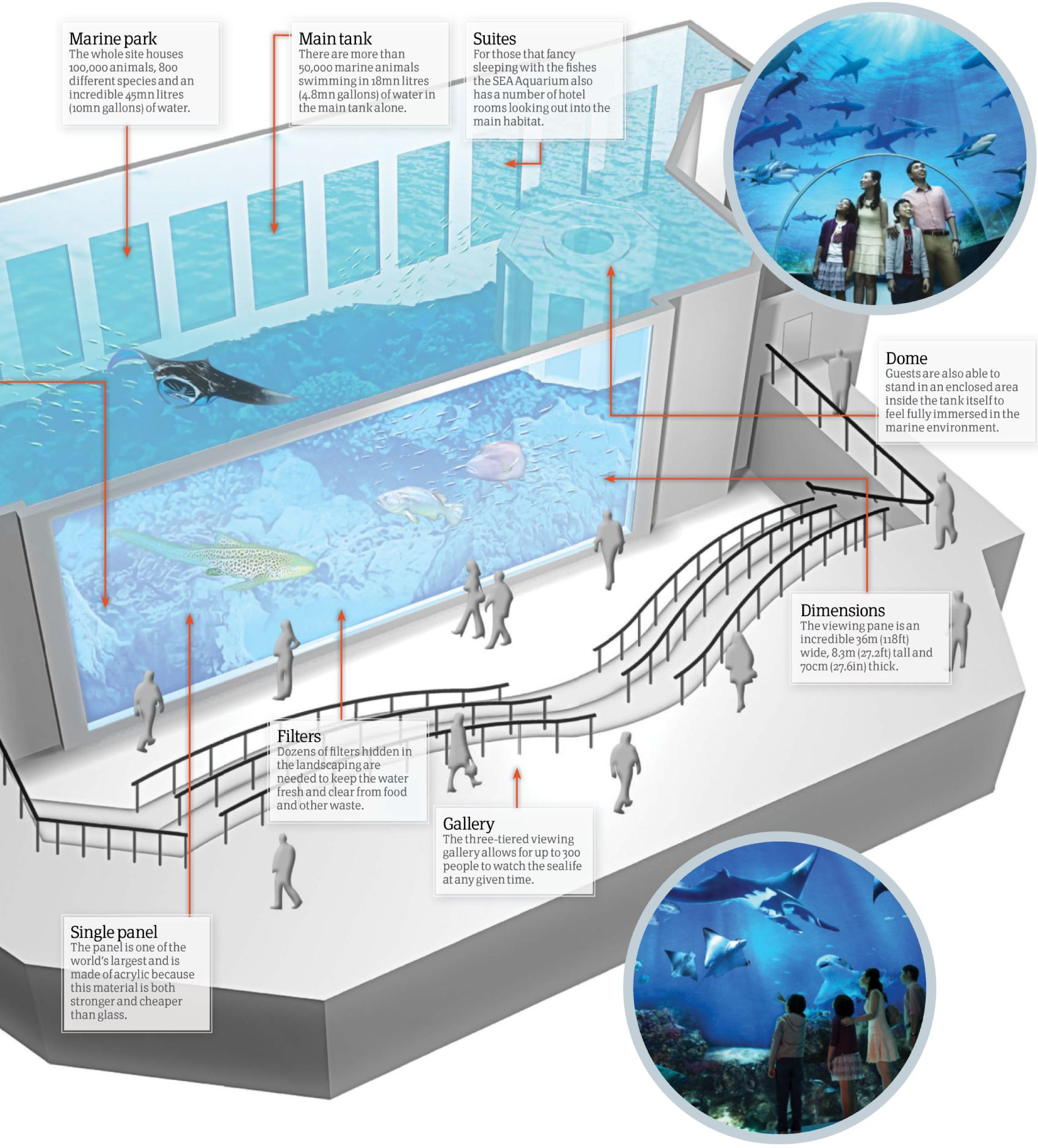
Take a tour of this supersized oceanarium in Singapore



Marine zones
In order to keep the various creatures separate and under the right conditions, they are split into ten zones and 49 different habitats.

Maintenance
The aquarium requires 15 vets and more than 40 divers to keep the animals fed and healthy, and to maintain the tanks.

Underwater dining
A restaurant overlooks the main tank so diners can continue to watch the sealife while eating – and, of course, only sustainable fish is served.



Marine park
The whole site houses 100,000 animals, 800 different species and an incredible 45mn litres (10mn gallons) of water.

Main tank
There are more than 50,000 marine animals swimming in 18mn litres (4.8mn gallons) of water in the main tank alone.

Suites
For those that fancy sleeping with the fishes the SEA Aquarium also has a number of hotel rooms looking out into the main habitat.

Dome
Guests are also able to stand in an enclosed area inside the tank itself to feel fully immersed in the marine environment.

Dimensions
The viewing pane is an incredible 36m (118ft) wide, 8.3m (27.2ft) tall and 70cm (27.6in) thick.

Filters
Dozens of filters hidden in the landscaping are needed to keep the water fresh and clear from food and other waste.

Gallery
The three-tiered viewing gallery allows for up to 300 people to watch the sealife at any given time.

Single panel
The panel is one of the world's largest and is made of acrylic because this material is both stronger and cheaper than glass.

© Resorts World Sentosa; Peters & Zabransky

How do mobile calls work?

The tech behind making phone calls

Our mobiles are portable gaming consoles, computers, alarm clocks and personal assistants all in one, but they're still pretty useful for calling someone without being tethered by a cord.

Unlike land lines, mobile phones work by sending electric signals via radio waves to mobile phone towers or masts. These masts pick up the signal, transmitting it along a network of masts until they reach the closest one to the phone receiving the call. Once there, the radio waves are finally beamed to the target phone and converted back into electronic signals and then into sound waves that enter the recipient's ear.

Mobile phone masts are placed several kilometres apart in rural areas but can be just a few hundred metres from each other in cities. There will be one mast per 'cell', which is the maximum area in which the mast can pick up a mobile signal. Hence the further away you are from a mast, the weaker the signal, so if you cannot get a signal at all, that means you aren't within range of a mast. As well as the large main masts, there are also a number of micro and picocells that are much smaller and have less coverage. However, these can pick up the radio waves and transmit them to the larger main masts, increasing the coverage without being an eyesore.

This network allows people to call wherever and whenever they want, only having to be within range of a tower. Even though satellites are required for long-distance calls that can't be transmitted from tower to tower, the process of making a phone call by relay is an amazing technological victory. ✽

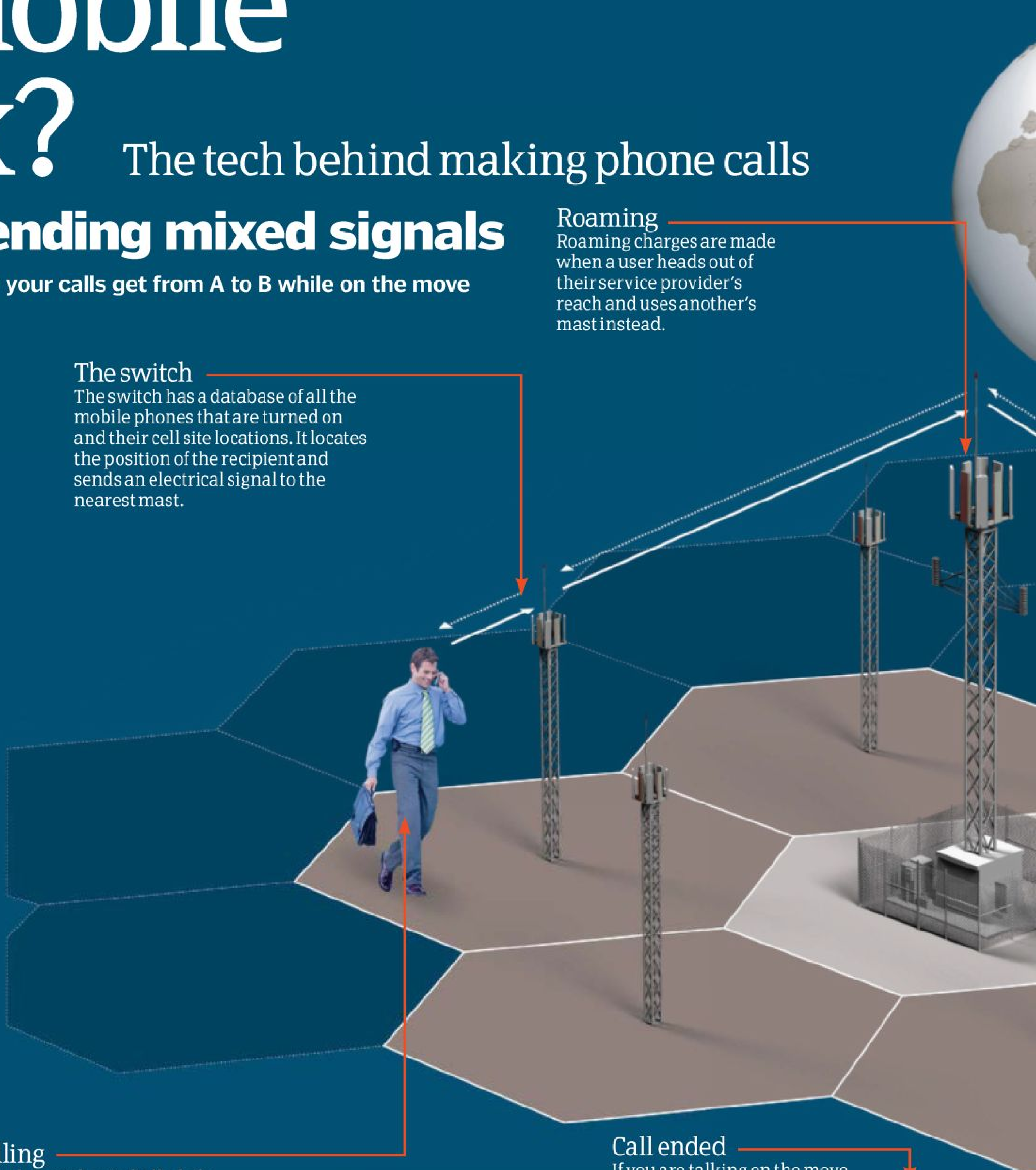
First smartphones

Most of you reading this will have a smartphone in your pocket or within arm's reach. The world's first smartphone is generally considered to be IBM's Simon Personal Communicator from the 1990s. It surpassed any other mobile at the time, as it sent and received emails, had a calculator, calendar, games and even a touchscreen, which was a revolutionary concept back then. It even had a basic predictive text function.

But it was not a commercial success, so the first smartphone to really take off was the Kyocera 6035, launched in 2001. It had an attached modem that wirelessly to the internet to send and receive emails and had 8GB of memory. It made work on the go a real possibility without the need for cables or heavy laptops.

Sending mixed signals

How your calls get from A to B while on the move



Roaming
Roaming charges are made when a user heads out of their service provider's reach and uses another's mast instead.

The switch
The switch has a database of all the mobile phones that are turned on and their cell site locations. It locates the position of the recipient and sends an electrical signal to the nearest mast.

Dialling
When the number is dialled, the antenna at the local cell site identifies the caller and the recipient. A cell site is where antennas and communications equipment are placed inside a mast or tower.

Call ended
If you are talking on the move and travel out of range of a phone mast, the phone call will cut off.

Motorola DynaTAC 8000X
Widely regarded as the first-ever commercial cellular phone.

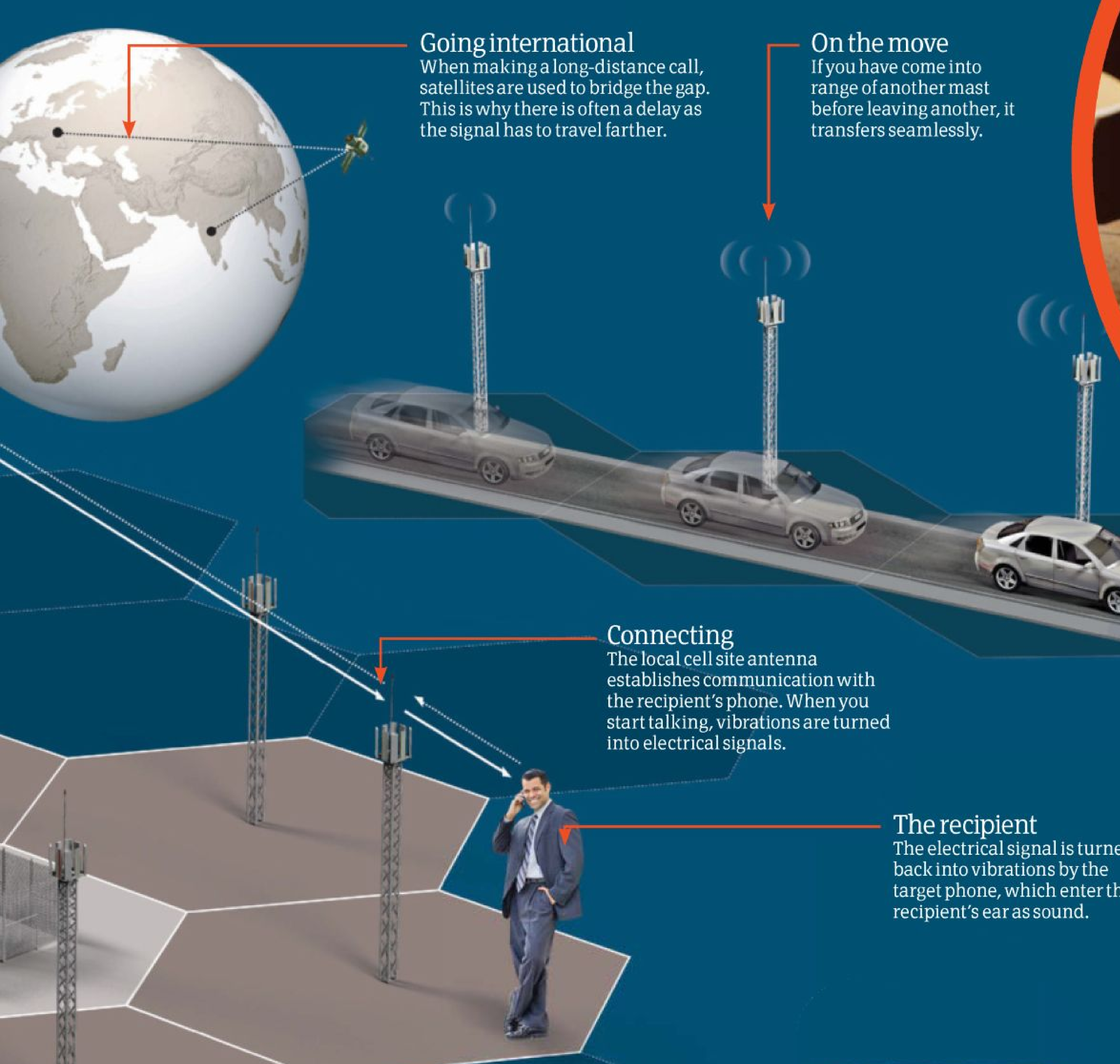
Simon Personal Communicator
First PDA/cell phone - included applications such as a calculator, calendar, address book, etc.

Motorola StarTAC
First clamshell cell phone – design reaches the cell phone at last.

Nokia 7110
One of the very first mobile phones to use Wireless Application Protocol (WAP).

Sharp J-SH04
One of the very first camera phones (released only in Japan).

Samsung SPH-M2100
The first MP3 cell phone.



Going international
When making a long-distance call, satellites are used to bridge the gap. This is why there is often a delay as the signal has to travel farther.

On the move
If you have come into range of another mast before leaving another, it transfers seamlessly.

Connecting
The local cell site antenna establishes communication with the recipient's phone. When you start talking, vibrations are turned into electrical signals.

The recipient
The electrical signal is turned back into vibrations by the target phone, which enter the recipient's ear as sound.

Kyocera QCP6035
The first successful 'smart' phone.

Panasonic P2101V
Among a group of the first third-generation cell phones available (with videoconferencing).

Motorola ROKR
First cell phone with iTunes.

iPhone
The first ever iPhone has a 8.9-cm (3.5-in) touchscreen and Wi-Fi Web access.

App attack

Apps are a crucial part of the modern mobile phone. It's estimated that the app market is worth a staggering £14.6 billion ($25 billion) worldwide, but which have had the biggest impact on the mobile scene?

Biggest buzz

The simple but insanely difficult *Flappy Bird* was an incredible success, netting independent creator Dong Nguyen £29,200 ($50,000) per day through advertising alone. He eventually took it down after he couldn't deal with the sudden pressure and fame.

Most downloaded

Probably the most famous app of all time, *Angry Birds* has been downloaded more than two billion times since it launched in December 2009. It has since spawned a cartoon series, console games and a planned feature film.

Highest grossing

Strategy and battle app *Clash Of Clans* has been at the top of the most recent charts in terms of revenue, gaining around £700,000 ($1.2 million) per day. However, *WhatsApp* netted its founders £11 billion ($19 billion) when they sold it to Facebook in 2014, dwarfing *Clash Of Clans'* cumulative revenue.

© Sol90 Images

Could the internet ever run out of space?

No. The internet isn't a thing in and of itself, it's a concept. All the computers in the world that are connected to the internet are themselves part of it. As the individual storage of each web server gets upgraded, so the capacity of the Internet gradually increases. There are always limits imposed by current technology – the total number of unique internet addresses, or the number of simultaneous connections that each server will accept. New protocols and hardware are continually developed to extend these limits, so the internet will to grow for as long as we need it to.

What is the most dangerous household appliance?

Cooking appliances are a major cause of accidental fires, causing more serious injuries and deaths than any other household devices. In the UK, they resulted in 33 fatalities and 4,100 injuries in 2011 and 2012. Roughly half were caused by stoves, while chip pans were the second-most likely item to spark a fire in the kitchen. Space heaters are a common culprit, going up in flames when their ventilation is blocked or wet clothes drip onto them. Lint buildup in dryers and electrical malfunctions in microwaves, freezers and dishwashers also cause many injuries due to fires.

What new tech was used at the Winter Olympics?

Some of the greatest technological leaps at the 2014 Winter Olympics in Sochi, Russia, were hidden in the athletes' suits and sleds. The US speed-skating team sported the world's fastest bodysuit, a collaboration between sports-clothing company Under Armour and aerospace engineering firm Lockheed Martin. 3D models of athletes in various skating positions were placed in Lockheed's wind tunnels to test hundreds of fabrics. The winning design had tiny rubber bumps and fins that reduced turbulence as the skater glides through the air. The US bobsled, luge and skeleton teams replaced old sleds with carbon-fibre models engineered by BMW Designworks out of bespoke composite materials developed by chemical company Dow. Wind tunnel testing delivered a lighter, smoother ride with tighter driver control. Even the curling brooms were given an upgrade, replacing brush heads with a smooth insulated fabric that raises the ice temperature nearly 30 per cent with a few short sweeps.

How does dry cleaning work?

Dry cleaning isn't actually 'dry' at all; it's a process that uses a liquid chemical solvent to remove dirt and stains from clothing that's easily damaged or shrunk. A normal washing machine soaks clothes in soapy water, agitates them, then rinses and spins them dry. Wool, silk and certain polyester fibres can shrink or lose colour in washing machines. In dry cleaning, clothes are sprayed with a liquid solvent and tossed gently in professional-grade machines that double as dryers. Most dry cleaners use a highly toxic, petroleum-based solvent called perchloroethylene, which cannot be touched or inhaled. 'Green' dry cleaners now use liquefied CO2. The final step is to press the clothes using industrial steam presses.

Can a computer compose music?

Certainly. Music composition isn't an entirely free-form process; even when humans compose music, they follow certain rules that define which notes belong in a scale and which chords belong in a key. It is quite possible to use computer algorithms to take those rules and a lot of other more subtle ones to create quite passable music. Band-in-a-Box is a Windows and Mac program that can improvise an accompaniment to any tune, while the Iamus computer cluster (right) at the University of Málaga, can compose a full-length classical symphony in a mere eight minutes!

Do you think we will ever be able to teleport people?

To say 'never' would be a strong word, but it's highly unlikely that teleportation of a human being á la Star Trek will ever be possible, given our current understanding of quantum physics and the known laws of the universe. To teleport a person, you would have to scan the exact location and physical properties of each of the 7 x 1027 atoms in the human body.

The first obstacle is the uncertainty principle, which states that the more accurately you measure one property of a quantum particle, the less accurately you can measure others. We could know an atom's location, for example, but not its momentum. Even if you could work around the uncertainty principle, you would need to scan and send an unimaginable amount of data – 10,000 times the current storage capacity of all of the world's computers – quickly enough to reconstruct living tissue. Plus, true teleportation requires the destruction of the original. Any volunteers?

> "True teleportation requires the destruction of the original"

© Thinkstock

How was the Millennium Eye built?

The Millennium Eye, or London Eye, is unique among observation Ferris wheels. All of the wheel's main components were built separately off-site and came from six different countries. They were then floated on barges up the River Thames to the Eye's location, which presented some challenges – once loaded onto trailers each capsule measured 4.9 metres (16 feet) tall, requiring careful route planning on their journey to avoid low bridges. The Eye was assembled horizontally on platforms in the river next to the site, with a massive floating crane lifting the rim sections into place. Once the wheel was assembled, the Eye was raised upright using hydraulic strand jacks. There was a hiccup as a temporary cable snapped, but over the course of a week the Eye was raised in stages and secured, before the capsules were attached.

What makes floodlights so bright?

Most floodlights use powerful gas-discharge bulbs. The same as fluorescent strip lights, these generate light by sending an electrical discharge through ionised gas. Selected for their high luminosity, metal halide floodlights produce up to 100 lumens per watt – five times as much as a traditional incandescent bulb. To illuminate a football pitch, about 200 of these lamps are mounted on columns. Floodlights require a great deal of energy; during a match the average stadium lighting uses roughly 1,350 kilowatt-hours – as much as the average UK household uses in 100 days!

* * *

How are electronic devices made waterproof?

Electronic devices like smartphones and tablets can be made waterproof by laminating the gadget with a nano-coating a thousand times thinner than a human hair. To apply the coating, the gadget is placed inside a vacuum chamber and exposed to a blast of gas containing a waterproof polymer. The polymer bonds to the surface of the device on a molecular level, coating both external components and the inside surfaces of headphone and Ethernet jacks. The result is a 100 per cent waterproof device that can play Angry Birds from the bottom of a fish tank.

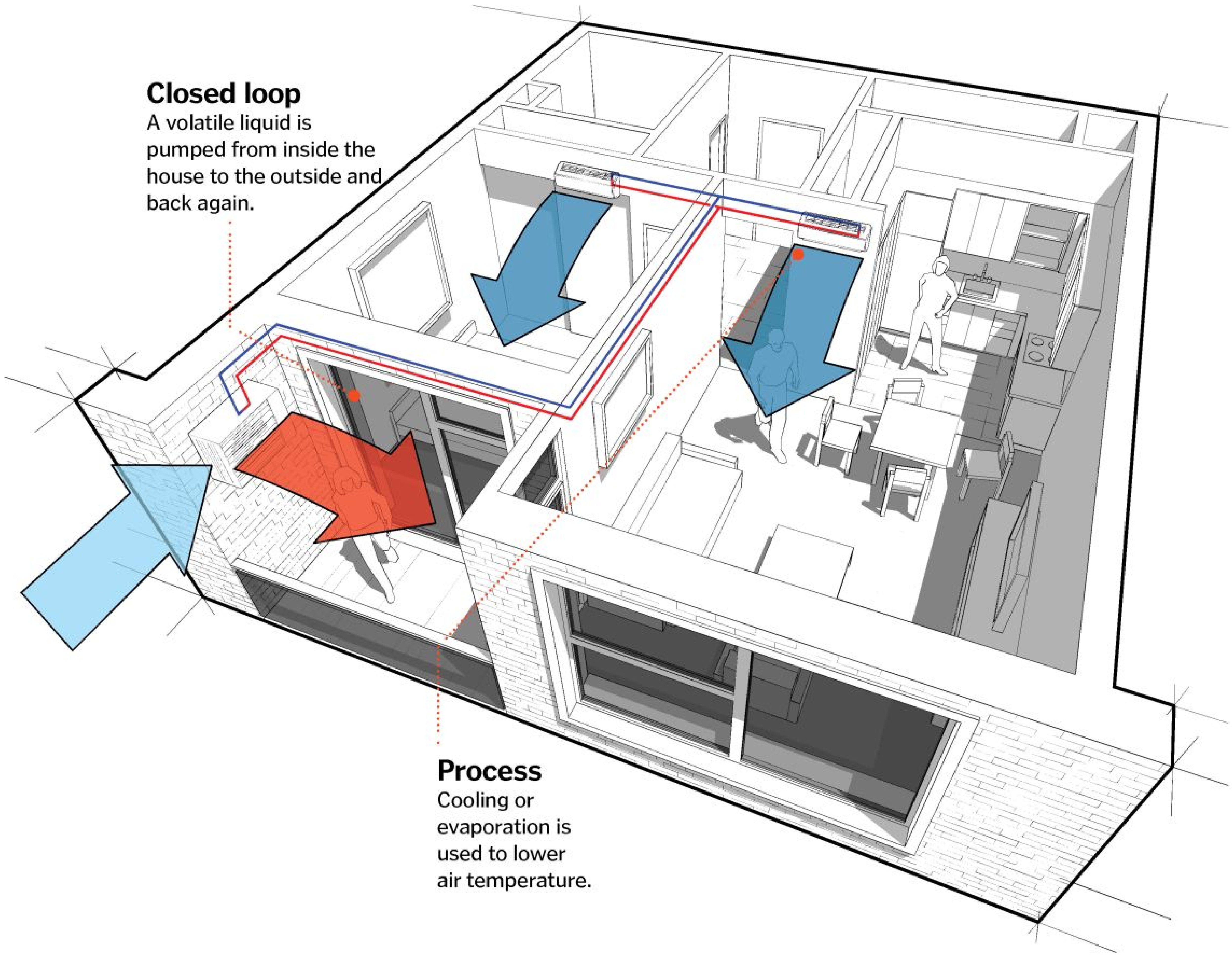
Why does the CERN particle collider have to be so big?

The Large Hadron Collider's colossal size limits the energy lost by particles as they hurtle around its 27-kilometre (16.8-mile) ring. The advantage of circular colliders is that they allow particles to zip around and around, with powerful magnets nudging them up to higher and higher speeds with each lap. But the change in direction as they bend around the track causes them to lose energy. The smaller the circle, the tighter the curve that the particles must follow and the more energy they lose. The LHC's gentle curves allow particles to reach almost the speed of light.

* * *

How do remote controls work and when were they invented?

The first television remote control – called "Lazy Bones" – was invented by the Zenith Radio Corporation in 1950 and connected to the TV by a wire. A wireless remote control came on the market five years later, but it didn't work very well. It worked by shining light onto a photoelectric cell on the TV, but had to be carefully aimed, and light from other sources could also cause your channels to change. If you've ever heard a remote control called a 'clicker', that originated with a remote made in 1956 that made a clicking sound when the buttons were pressed. They emitted ultrasonic sounds received by a microphone on the TV, but this system wasn't ideal either. So in the 1970s, more complex remotes that used infrared technology were developed. The latest remotes use Bluetooth or radio waves, eliminating the need for aiming the remote directly at the television.


Closed loop
A volatile liquid is pumped from inside the house to the outside and back again.
Process
Cooling or evaporation is used to lower air temperature.

How does air conditioning work?

An air conditioner is a closed loop that pumps a volatile liquid from the inside of the house to the outside and back again. As the liquid passes through the indoors leg of the circuit, the heat from the room makes the liquid evaporate. This absorbs heat energy as the molecules change from liquid to gas phase. The coolant vapour is then pressurised by a compressor to make it even hotter and pumped through the outdoors section of the loop. As the gas is hotter than the outside temperature, it loses heat to the environment and at this higher pressure, it condenses back into a liquid. It can now be pumped back to the inside, through an expansion valve, which reduces the pressure. This boils off some of the liquid, which cools it back down to the point where it is colder than the room and the cycle repeats.

* * *

Who invented the first ever digital camera?

Astonishingly, the first-ever digital camera was invented way back in 1975 by an electrical engineer called Steven Sasson who worked at Eastman Kodak, a US technology company. Here he not only invented the camera, but also built it using a charge-coupled device image sensor and various other parts he collated from the lab and elsewhere. The camera weighed 3.6 kilograms (eight pounds) and recorded 0.01-megapixel black-and-white photos to a cassette tape, from which data was read and the images displayed on a television screen. It took almost half a minute to process the first photo from it.

How does LiFi internet work?

LiFi is just like WiFi, except that instead of sending network data using radio waves, it uses light. Visible light and radio waves are both electromagnetic waves but the visible part of the spectrum is about 10,000 times wider than the radio frequencies allocated to WiFi. Current LiFi systems are still experimental but they could eventually be incorporated into phones and gadgets using a single LED bulb that flickers on and off too fast for the eye to detect. Although LiFi won't travel through walls, it doesn't need direct line of sight because it can work by reflecting off surfaces.

* * *

What would happen if my microwave had a hole in it? Would radiation leak into the kitchen?

For radiation to leak out of your microwave, the hole in the oven would have to measure 12 centimetres (4.7 inches) or more across. Like visible light, microwaves are a form of electromagnetic radiation and can pass through paper, plastic or glass, but reflect off the oven's metal walls. A household microwave produces radiation with a frequency of 2,450MHz, optimised to excite water molecules and heat up food. These waves have a wavelength of 12 centimetres (4.7 inches), meaning they cannot pass through gaps smaller than that. Microwave doors are typically made of glass lined with a metal wire mesh, which allows you to check up on your dinner without letting radiation out. If there was a sufficiently large hole, microwaves could escape. However, the waves produced by a microwave oven are non-ionising, carry relatively little energy and would dissipate quickly, making it unlikely they would cause significant harm.

Transport

Q&A

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Can cars drive by themselves?

Self-drive cars use a host of new technology to present a novel concept of travel for road users

The cars of tomorrow won't need steering wheels, an accelerator or a brake pedal; they're autonomous and don't require any human input. What's more is that they are already on the road, with car company Volvo unleashing 100 of them on public roads of Gothenburg, Sweden, in a two-year project.

An autonomous (known as 'self-drive') vehicle works mainly thanks to a wealth of on-board radars, sensors and cameras that continuously 'read' the car's surroundings to build a picture of the road ahead. While radars and sensors monitor everything from the proximity of other cars on the road to the whereabouts of cyclists and pedestrians, a forward-facing camera interprets highway instructions from road signs and traffic lights. All of this information is continuously fed to the vehicle's on-board computer, which uses the data to action appropriate inputs into the car's speed and trajectory within milliseconds. Meanwhile, advanced GPS technology is constantly used to clinically navigate the vehicle along a precise route.

An autonomous vehicle prototype, otherwise known a self-driving car, looks fairly similar to a contemporary human-driven vehicle. Built-in sensors dotted around the car emit frequencies that bounce back off objects – much in the same way parking sensors work on executive saloons now – to provide a rationale of how close things such as curbs, pedestrians and other vehicles are to the self-driving car. The processing computer and GPS system are stored out of sight, leaving the roof-mounted LIDAR (Light Detection and Ranging) as the only discerning differentiation from the norm.

This rotating camera sends out lasers and uses the reflected light to effectively build a 3D picture of the car's position within the current environment. The information received from these 'bounced' light rays is sent to the main on-board computer. In the cabin, an occupant is treated to a screen showing the route, plus there's an emergency stop button that will immediately pull the car over if needed.

Although technology giant Google has led the way in terms of evolving self-drive technology, automotive manufacturers such as BMW and Nissan have placed considerable resources for research and development into the technology of their own autonomous vehicles. These test vehicles tend to be adapted versions of current human-driven vehicles and as soon as a person touches any of the foot pedals or steering wheel, the system immediately cedes control back to the driver.

Although Google began its autonomous vehicle mission by adapting already homologated Toyota and Lexus cars as far back as 2010, its latest prototype is arguably the best yet. So far, it has proved to be markedly safe compared to human-input driving, as driver fatigue or alcohol impairment will play no part in getting from A to B. ▶

All aboard the road train

A further development on the self-drive principle for a single car has already been implemented on a series of vehicles, allowing them to travel autonomously and in tandem as a group. The concept was an idea borne from the 'SARTRE' project, which stands for Safe Road Trains for the Environment. Pioneered by Swedish manufacturer Volvo and a group of technological partners, their system uses an array of radar, camera and laser sensors linked together by wireless technology to allow autonomous vehicles to travel together in a train-like platoon. At the front of the platoon is a dedicated lead vehicle – driven by a professional driver, which is followed autonomously by the trailing vehicles. This is all being done in a bid to reduce the number of accidents caused every year by driver fatigue.

The technology has already proved plausible after tests were carried out over 200 kilometres (124 miles) of road near Barcelona, Spain, in May 2012, with three cars automatically following a truck driven by a human being. The road train successfully melded autonomous technologies with car-to-car 'communication' to ensure the three self-driven vehicles remained in line throughout the whole test – and crucially, with no collisions.

Volvo's SARTRE project in action on a public road

Self-driving trucks

Family cars aren't the only vehicles currently receiving the autonomous treatment. Mercedes is developing the self-drive concept for its fleet of heavy-haulage trucks.

And, different to the realms of pioneering software of a Google car, Mercedes is simply evolving some of the tech already found in their new luxury saloons instead.Cruise control, lane assist, auto braking and stability control – all available on the Stuttgart company's new S-Class – has been synced to a radar on its Mercedes-Benz Future Truck 2025 prototype, which scans the road ahead by up to 250 meters and communicates with the established systems to keep the lorry moving safely, without input from a driver. Developers say the system will drive more economically than a human, saving fuel, while increasing productivity as the vehicle will be able to travel for longer periods than what daily driver limits will currently allow.

Self-drive technology could revolutionise truck transport

To heighten safety even further, Google is experimenting with flexible windscreens and a front made of foam-like material to protect pedestrians on impact, should the worst happen. These cars have also been limited to a relatively tame 40-kilometre (25-mile)-per-hour top speed while the project is still in the development stage.

However, while the theory of self-drive cars is relatively straightforward – a computer actions an input for a mechanical device to implement – the unpredictability of hazards when driving is the biggest challenge for an autonomous vehicle to overcome. Much like a human having plenty of practice ahead of their driving test, the process for 'training' self-drive cars is to evaluate every single possible hazard perception scenario that could arise on the road and input them into the car's computer for the best course of action to take.

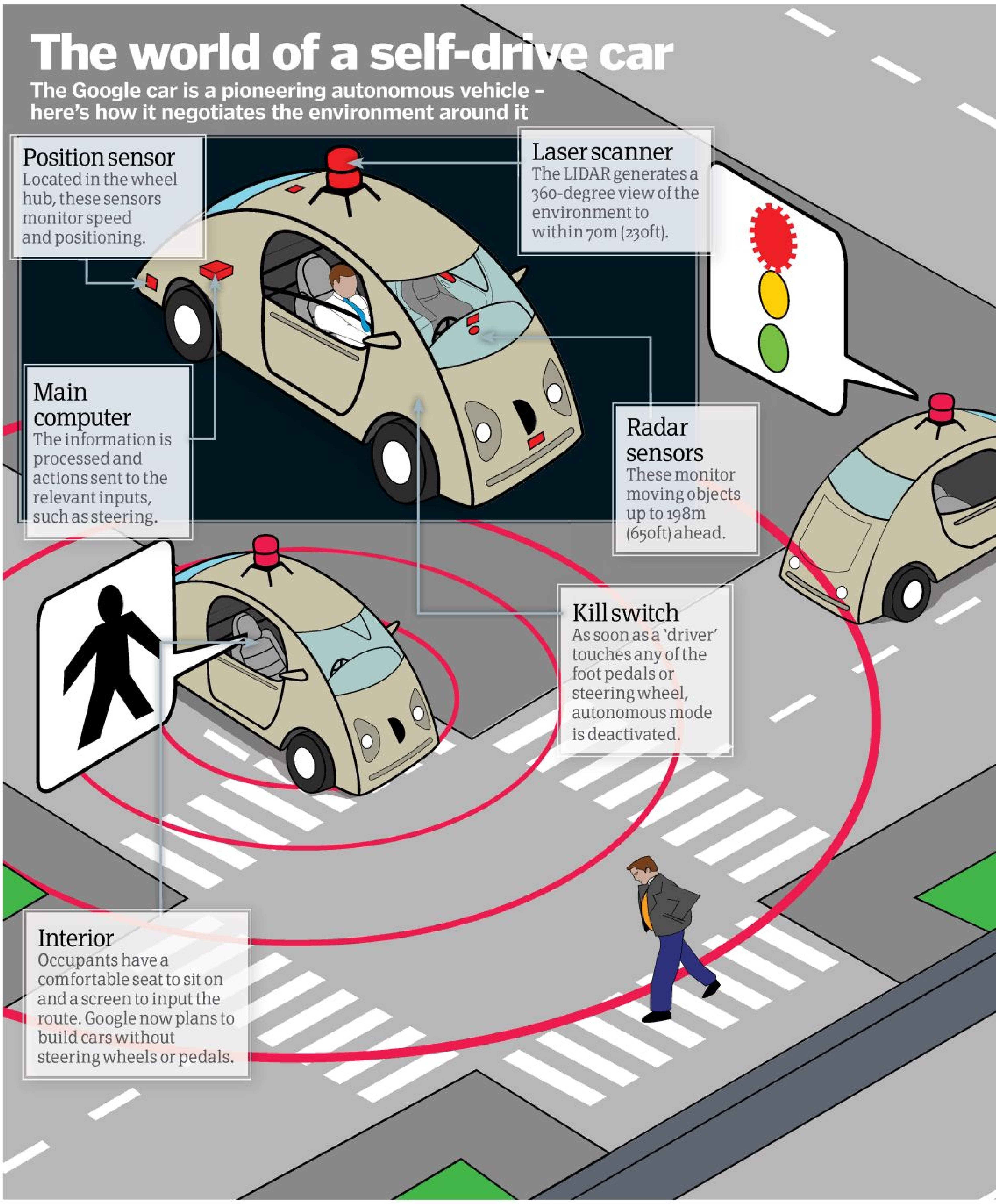
> "While the theory of self-drive cars is relatively straightforward... the unpredictability of hazards when driving is the biggest challenge"

There are further limitations to the technology. Currently, a Google car cannot drive on a road that hasn't been mapped by the company's Maps system, so taking a self-drive car for a spin around your newly built suburban housing estate could prove somewhat problematic. Also, sensors on the car currently struggle to pick up on lane markings when roads are wet or covered in snow, making autonomous driving in adverse conditions particularly hazardous.

Companies are seeking to address these shortfalls, with safety drivers currently testing their self-drive vehicles in a variety of situations on the road every day and providing feedback on how to further improve the concept. Google even admits that its self-drive prototype is built with learning and development and not luxury in mind, so their own vehicle is currently bereft of any real creature comforts. However, if the blueprint for an autonomous car proves successful, that could well change and we could soon see motorways packed with moving vehicles where every occupant is kicking back and watching a film, checking emails, or reading How It Works magazine.

The world of a self-drive car

The Google car is a pioneering autonomous vehicle – here's how it negotiates the environment around it



Position sensor
Located in the wheel hub, these sensors monitor speed and positioning.

Laser scanner
The LIDAR generates a 360-degree view of the environment to within 70m (230ft).

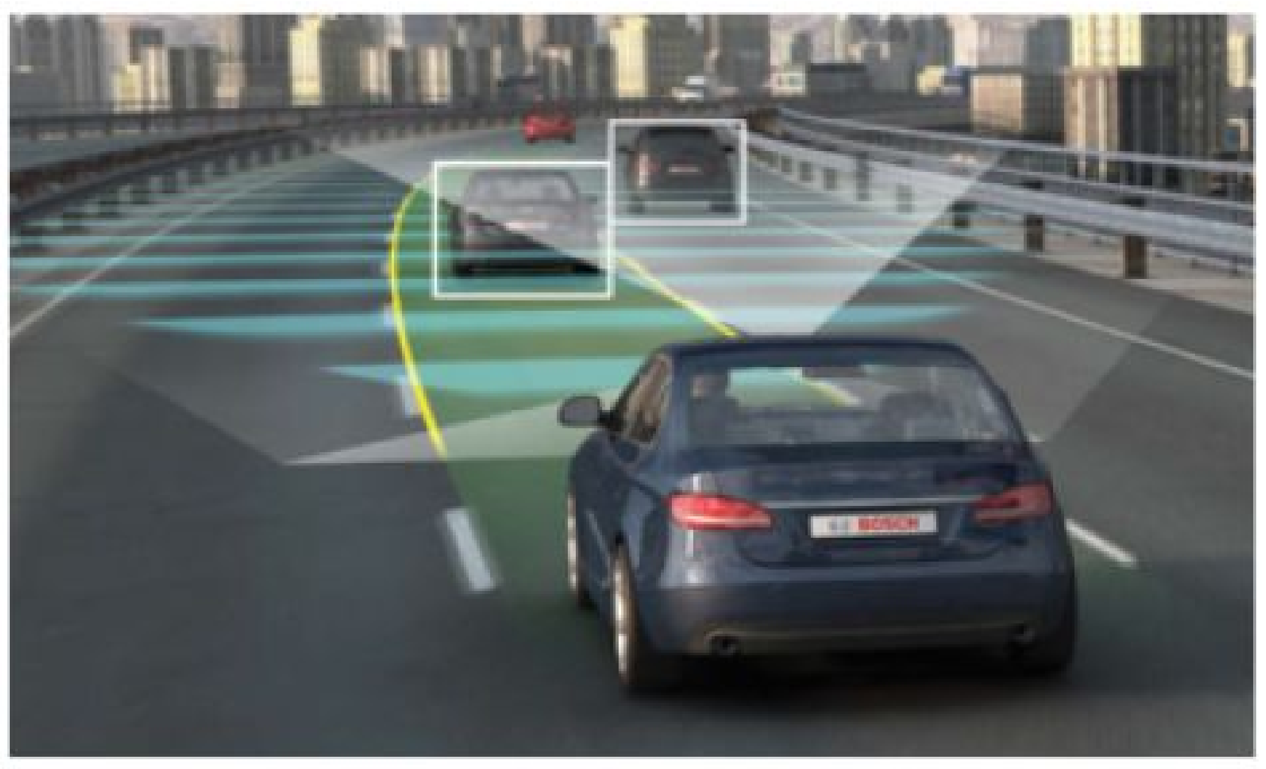
Main computer
The information is processed and actions sent to the relevant inputs, such as steering.

Radar sensors
These monitor moving objects up to 198m (650ft) ahead.

Kill switch
As soon as a 'driver' touches any of the foot pedals or steering wheel, autonomous mode is deactivated.

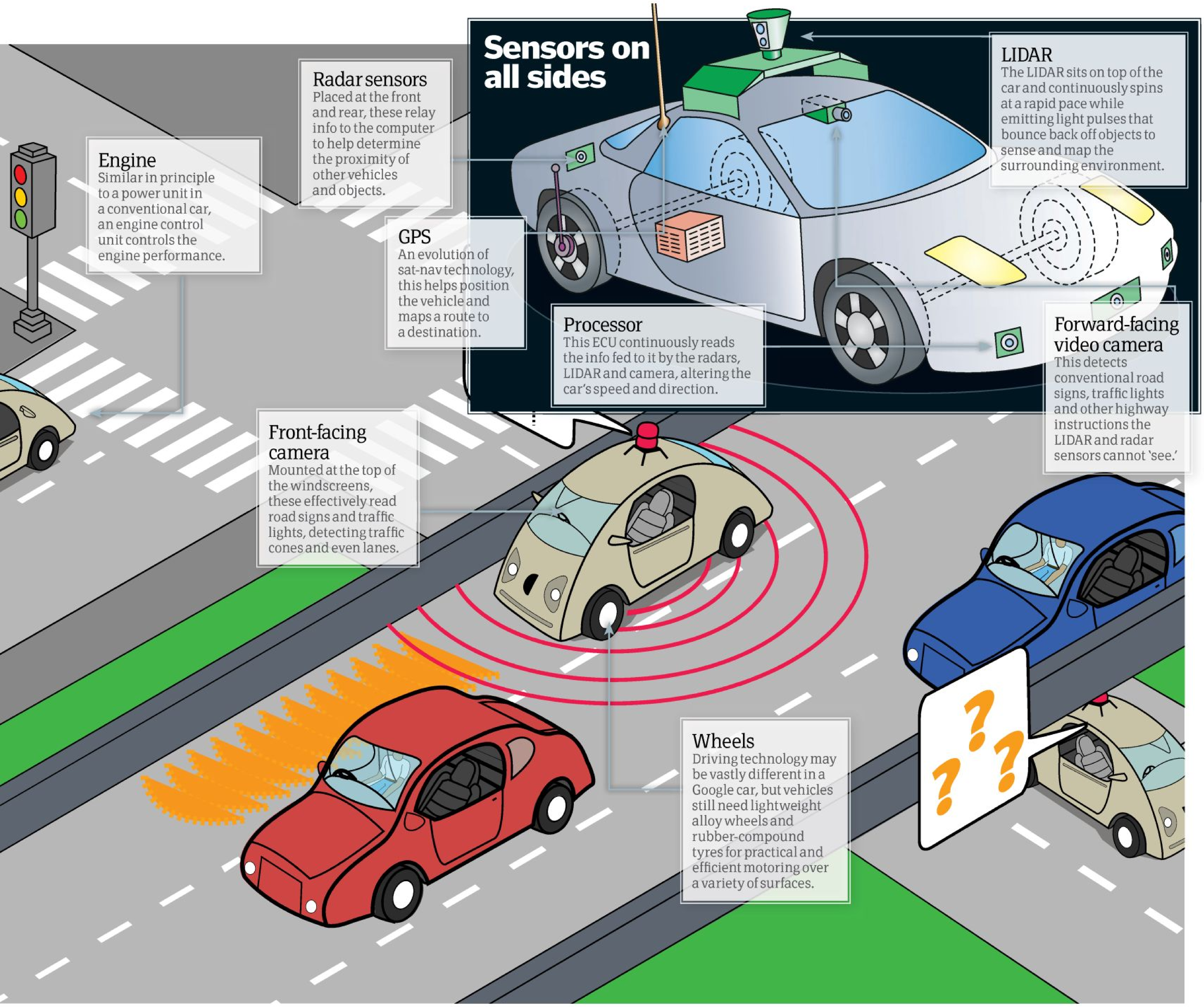
Interior
Occupants have a comfortable seat to sit on and a screen to input the route. Google now plans to build cars without steering wheels or pedals.

Autonomous tech available now



Predictive braking
Available on most modern cars, a radar-controlled Electronic Stability Program (ESP) continuously analyses the traffic ahead and, if the driver fails to react to the proximity of another object, it automatically stops the car.

Lane assist
This stops a vehicle from drifting between lanes. If the front camera detects the vehicle has unintentionally deviated out of a motorway lane, it'll input counter-steer at the wheel to ensure the vehicle returns to its lane.



Sensors on all sides

LIDAR
The LIDAR sits on top of the car and continuously spins at a rapid pace while emitting light pulses that bounce back off objects to sense and map the surrounding environment.

Radar sensors
Placed at the front and rear, these relay info to the computer to help determine the proximity of other vehicles and objects.

Engine
Similar in principle to a power unit in a conventional car, an engine control unit controls the engine performance.

GPS
An evolution of sat-nav technology, this helps position the vehicle and maps a route to a destination.

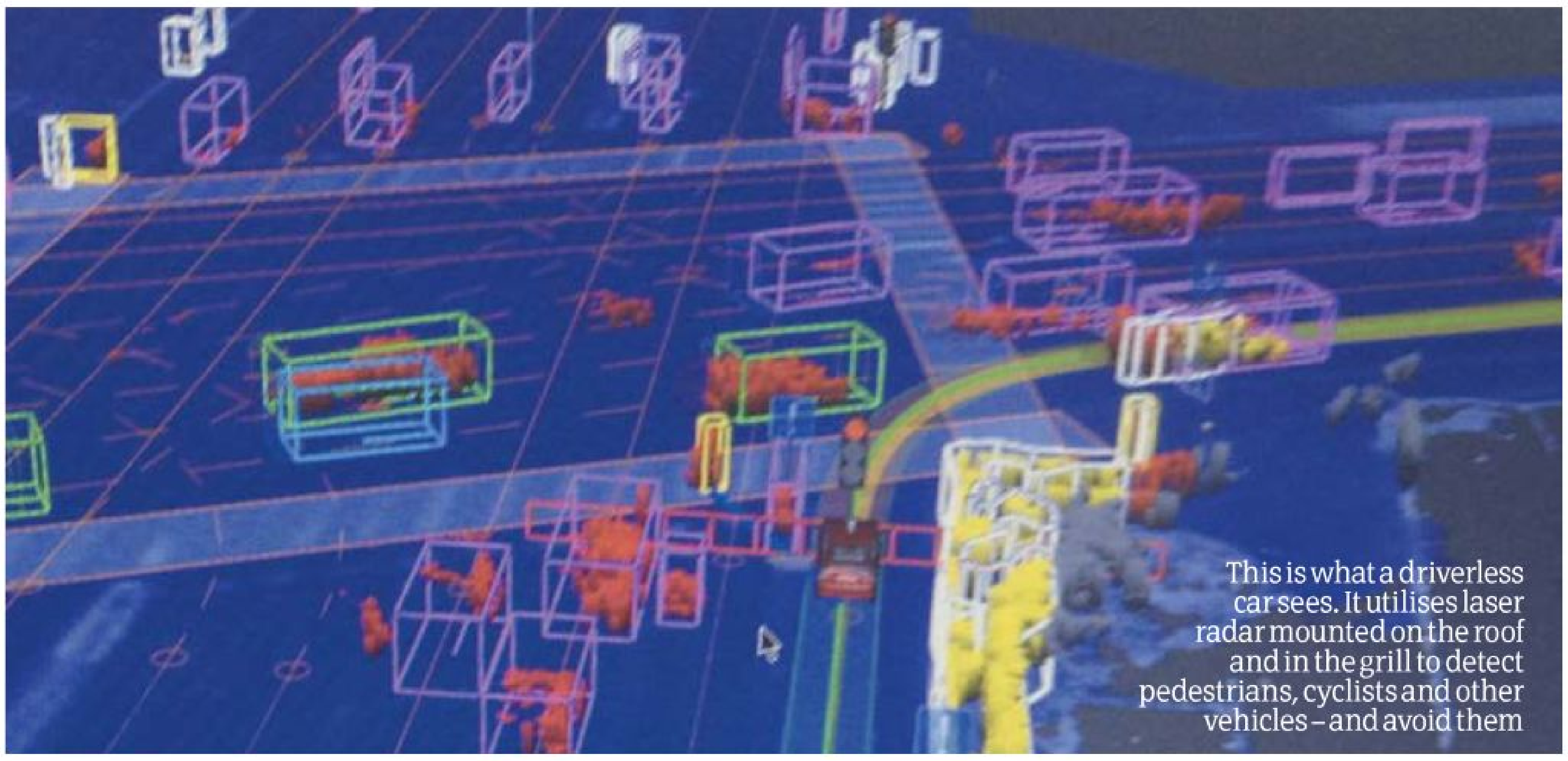
Processor
This ECU continuously reads the info fed to it by the radars, LIDAR and camera, altering the car's speed and direction.

Forward-facing video camera
This detects conventional road signs, traffic lights and other highway instructions the LIDAR and radar sensors cannot 'see.'

Front-facing camera
Mounted at the top of the windscreens, these effectively read road signs and traffic lights, detecting traffic cones and even lanes.

Wheels
Driving technology may be vastly different in a Google car, but vehicles still need lightweight alloy wheels and rubber-compound tyres for practical and efficient motoring over a variety of surfaces.

Active high beam control
Porsche and Volvo have introduced active high beam control, which dips the main headlight beam when sensors detect oncoming traffic at night. This avoids dazzling other road users with glare from the main beam.



This is what a driverless car sees. It utilises laser radar mounted on the roof and in the grill to detect pedestrians, cyclists and other vehicles – and avoid them

© Bosch; REX; Peters & Zabransky

Which is the world's fastest roller coaster?

Experience the thrill of an F1 car from over 50 metres in the air

Most of us will never know what it's like to hit top speed in a Formula One car, but you can have something better – by experiencing that thrill while rising and falling on the world's fastest roller coaster.

It's called Formula Rossa and can be found at Ferrari World in Abu Dhabi. Not only does it go from zero to 100 kilometres (62 miles) per hour in a face-flattening two seconds, it also reaches a dizzying 240 kilometres (149 miles) per hour in under five seconds, topping the world's second-fastest 'coaster by 21mph.

Those brave enough to try will experience forces of 1.7g when accelerating and an incredible 4.8g around the corners, which is similar to the forces a driver will confront in a Grand Prix race at Silverstone or Monaco. Dedicated Formula One fans may recognise a few of the corners too, as they've been inspired by some of the real-life ciruits' famous twists and turns.

The roller coaster is able to reach its mind-boggling speed due to the wealth of technology underneath the track. 48 hydraulic motors generate an immense amount of power before transferring it to the catch car, which is hurled along the track, carrying the train with it. Eventually the catch car stops, catapulting thrill seekers to those immense speeds.

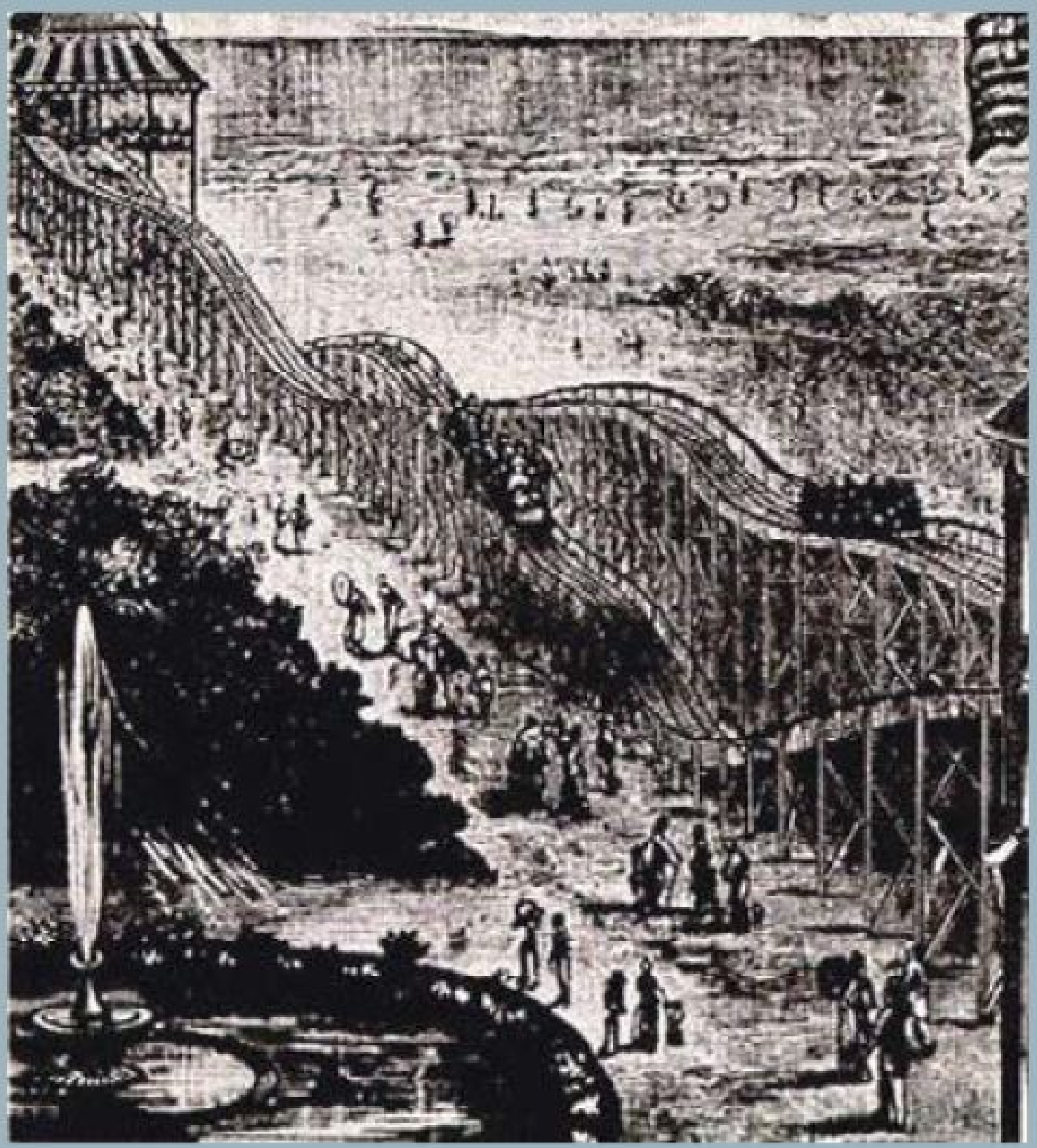
Only the brave need apply.

The ups and downs of the roller coaster

The roller coaster dates back over 350 years as 17th-century Russians whiled away the winter on ice slides. These were big wooden slides covered in ice that people threw themselves down before flying back up as it curved, much like a half-pipe.

The roller coaster we know and love today begun to take shape in the 19th century as an undulating track was built and patrons rode on a wheeled cart. Safety then became a concern and 1817 saw a French construction with wheels that locked onto the track. France was also the location for the first-ever loop-the-loop coaster, as people could experience the thrill of a four-metre (13-foot) loop.

As with many things, the news spread to the United States and became a massively popular tourist attraction as La Marcus Adna Thompson took the model of a railroad and made it extreme! Opened in 1884, the Switchback Railway made Thompson hundreds of dollars every day, leading to an explosion of interest in the area. Coney Island in New York got in on the act with its own spectacular thrill ride and from there, the race to become the biggest and best took off.

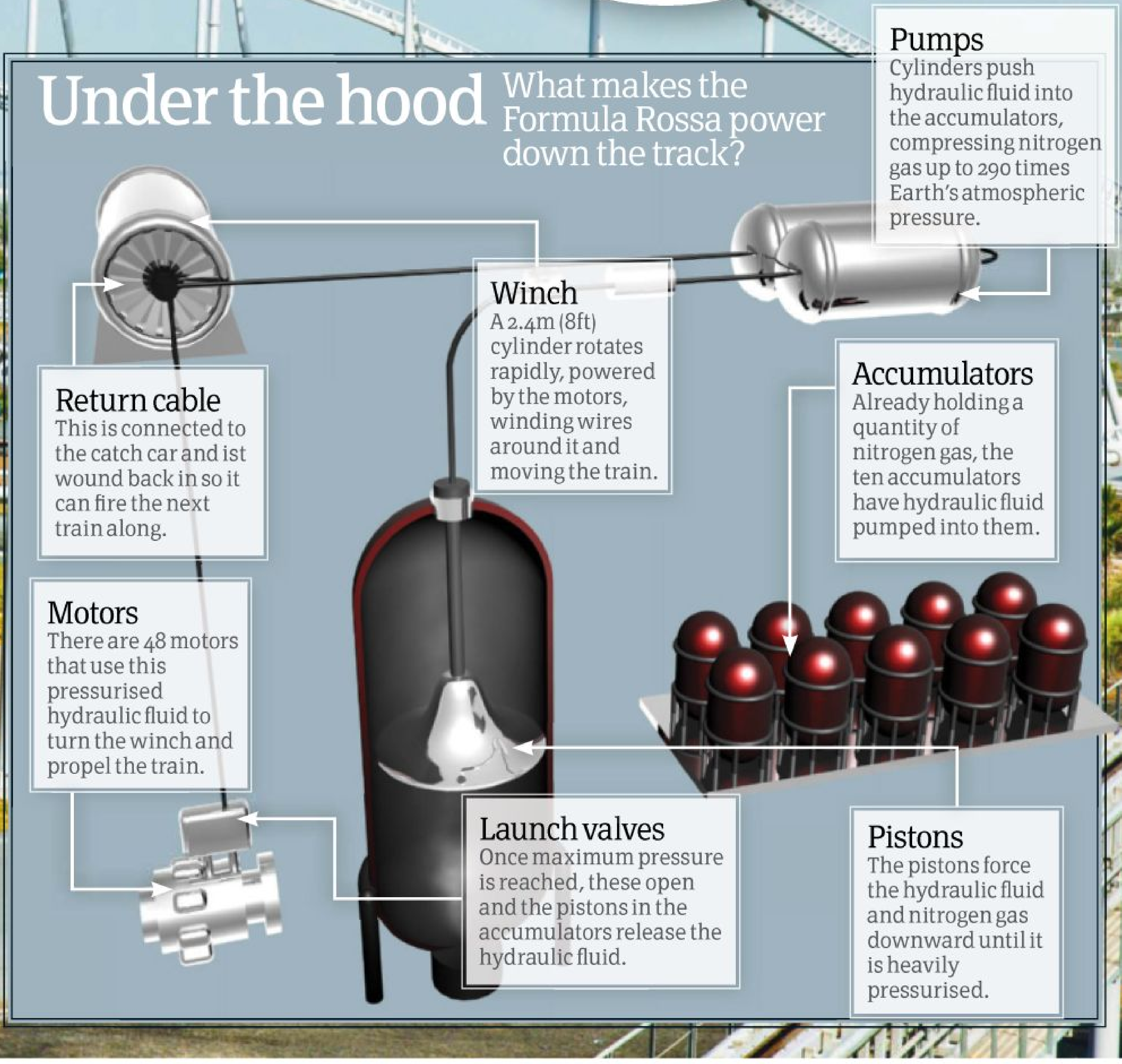


The Switchback Railway was a revolutionary amusement ride

Ferrari World in Abu Dhabi is the world's largest indoor theme park

Under the hood

What makes the Formula Rossa power down the track?



Pumps
Cylinders push hydraulic fluid into the accumulators, compressing nitrogen gas up to 290 times Earth's atmospheric pressure.

Winch
A 2.4m (8ft) cylinder rotates rapidly, powered by the motors, winding wires around it and moving the train.

Return cable
This is connected to the catch car and ist wound back in so it can fire the next train along.

Accumulators
Already holding a quantity of nitrogen gas, the ten accumulators have hydraulic fluid pumped into them.

Motors
There are 48 motors that use this pressurised hydraulic fluid to turn the winch and propel the train.

Launch valves
Once maximum pressure is reached, these open and the pistons in the accumulators release the hydraulic fluid.

Pistons
The pistons force the hydraulic fluid and nitrogen gas downward until it is heavily pressurised.

Head to head

	Formula One	Formula Rossa
SPEED	370 km/h	240 km/h
0-100KM/H	1.7 seconds	2 seconds
WEIGHT	691 kilograms	8.8 tons
SEATS	1	16
STEERING WHEEL	20+ CONTROLS	NONE REQUIRED

© Peters & Zabransky; Alamy

How do portholes get their strength?

How ships' windows have been made for centuries

Portholes have provided a window onto the seas for hundreds of years. The window's glass is a combination of silica, ash and lime, which is mixed together and then heated and cooled several times in huge furnaces. This is known as tempering and it strengthens the glass. On submarine vessels, the portholes can be several inches thick.

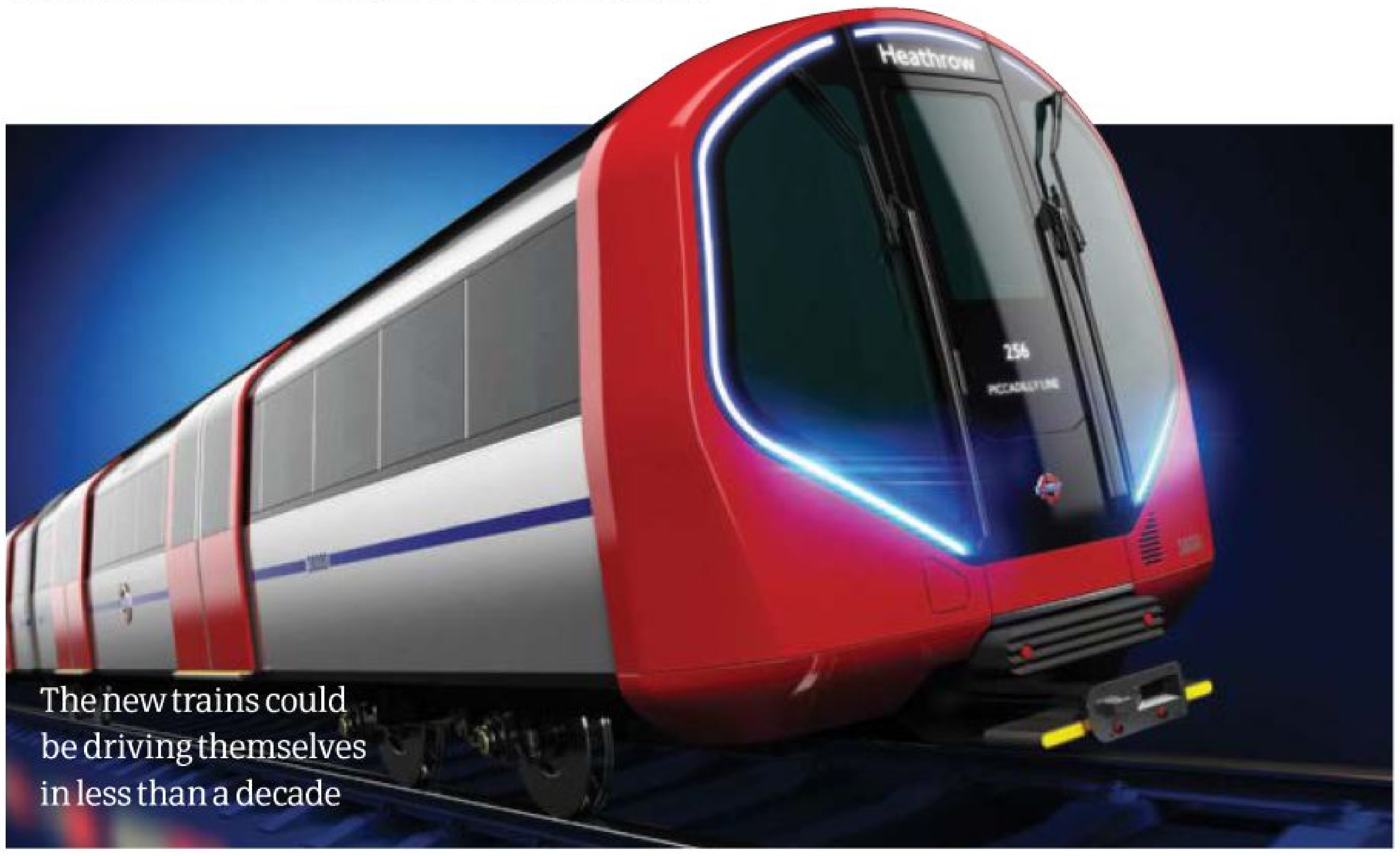
Brass and bronze are the main types of frame used because of their resistance to rust and pressure. The porthole is placed onto the ship, over a rubber sealing gasket to prevent water leakage and bolted in place.

They have been used on ships ever since cannons on Henry VI's ships became too large for traditional mounting. Shipbuilder James Baker made holes in the side of the ship and poked the cannons through. When the cannons were not in use, hinged covers would be put over the holes. Even though ships no longer have cannons on them, portholes are still useful for passenger ships as windows during particularly bad weather. ✿

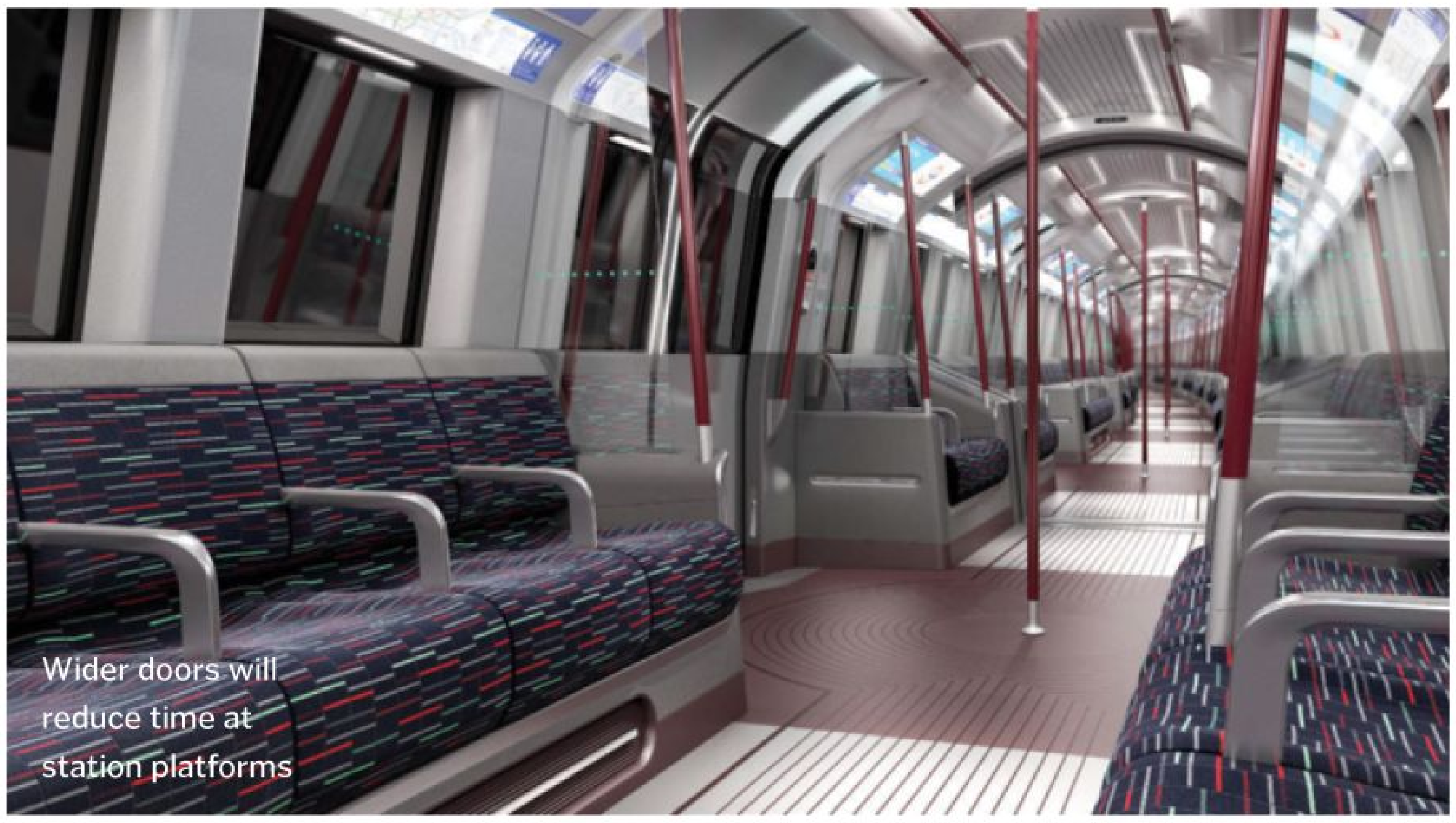
> "The glass is a combination of silica, ash and lime, heated and cooled several times in huge furnaces"

Can the Tube be driverless?

How will the Tube trains of tomorrow cross London?



The new trains could be driving themselves in less than a decade



Wider doors will reduce time at station platforms

London's Tube lines may still be a relic of the Victorian age, but its trains could soon be amazing driverless machines, packed with digital screens and air-cooled cars. The new designs, which could be in place as early as 2022, have a number of features that will improve the passenger experience. These include air-cooled carriages, digital screens that display real-time travel information and will be made up of walk-through carriages, increasing capacity on lines by up to 60 per cent.

The biggest development, though, is the fact that they could be self-driving. The trains, which will run on the Piccadilly, Bakerloo, Central and Waterloo & City lines, could run autonomously in just eight years' time.

One of the other developments in store is wider doors to speed up station transitions and tall barriers with sliding doors on the platform edges to increase safety. ✿

© Thinkstock; PriestmanGoode

What's the future of Antennas?

Revolutionising the humble aerial for a new age

Wi-Fi, Bluetooth and 3G can send the lowly bog-standard car antenna into a spin. In order to handle today's abundance of portable and wireless technology, a new type of antenna will soon be racing its way into our vehicles. It has been developed and issued by the European Commission's Intelligent Car Initiative.

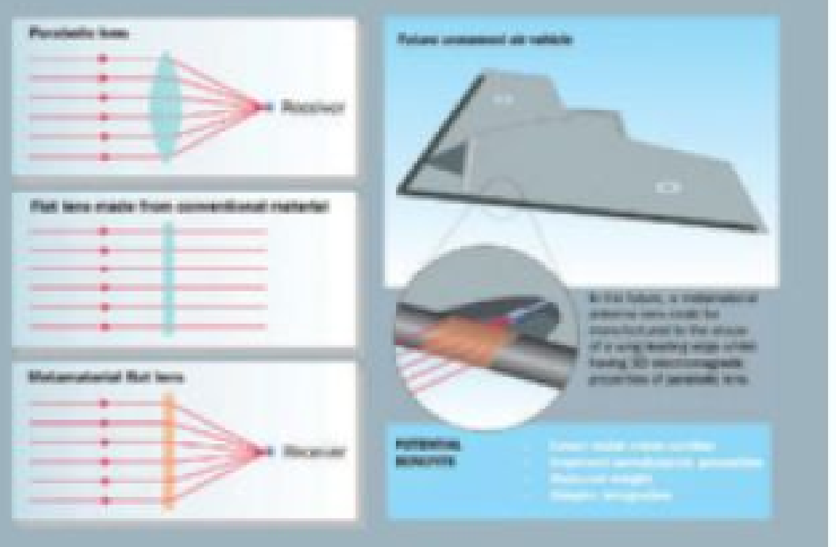
This new system can handle not only modern radio frequencies like DAB but also the latest in satellite-navigation technology and internet connections. Millimetre wave-integrated antennas and other smart antennas will connect to infrastructure systems to alert the driver to upcoming hazards and traffic information among other things.

The antenna must have a large set of features. The bandwidth needs to be wide so it can access as many frequencies as possible and the polarisation must match the gadget it is trying to connect to. To ensure this is possible, a new 'antenna hub' has been devised to maximise connectivity. This hub will connect any relevant gadget, whether it be for navigation, music or internet.

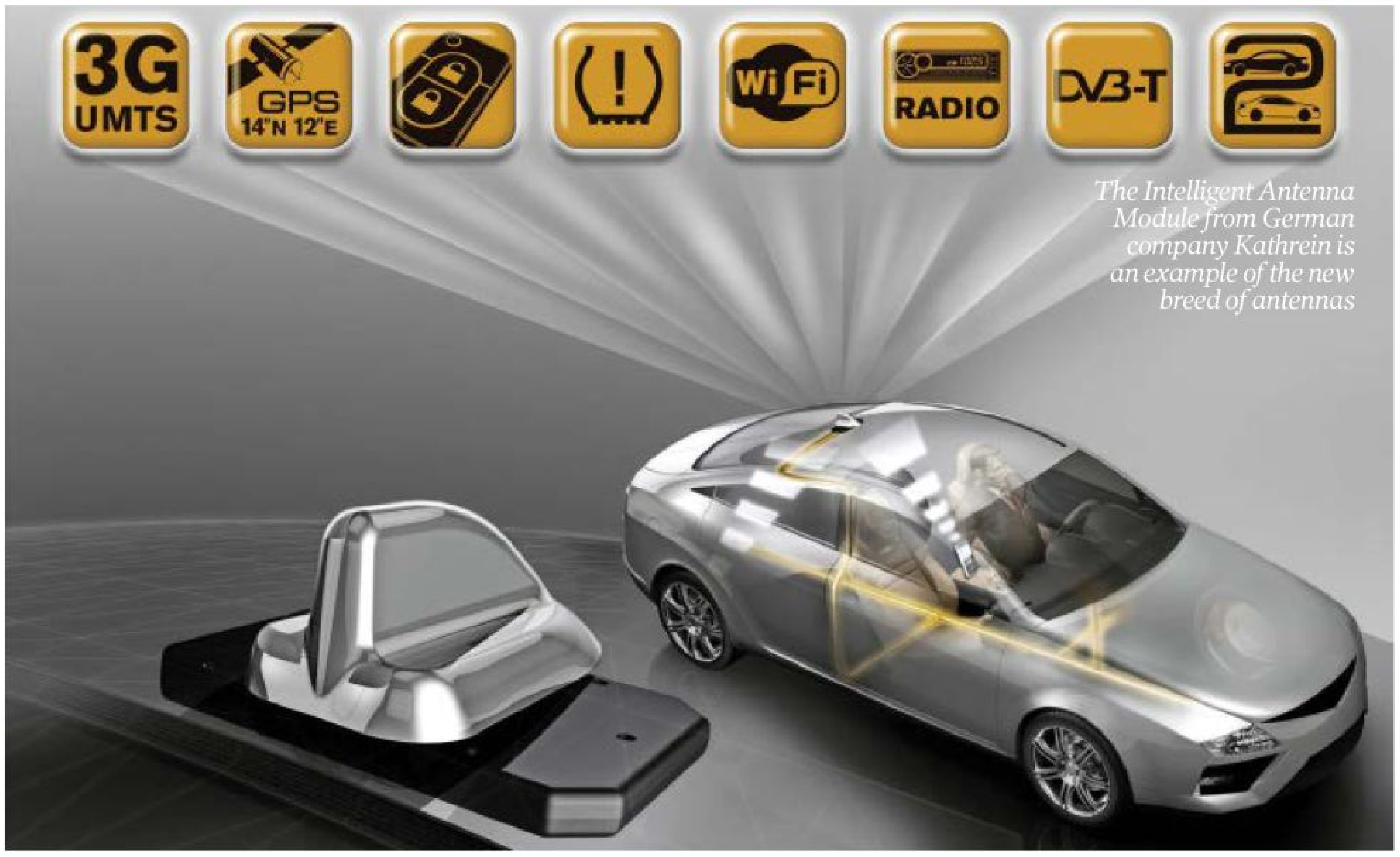
The advanced Taranis could utilise new antenna tech

Military antennas

A new type of antenna is being developed by BAE Systems to make aircraft even more aerodynamic. The new flat lens is far superior to the curved parabolic and conventional flat lenses, as now only a single antenna will be used to save weight and enhance the streamlined capabilities of the craft. The process is known as transformation optics and the best properties of a curved lens (electric conduction) are accommodated by the best features of a flat lens (aerodynamics). Large bandwidths will be accessible without compromising speed and handling.



An innovative new flat lens will have all the properties of a curved one



The Intelligent Antenna Module from German company Kathrein is an example of the new breed of antennas

Will our roads glow in the dark?

Streetlights to be switched off in favour of luminous paint?

Rather than use energy-sapping street lighting, glowing lines will illuminate at night to highlight the road ahead

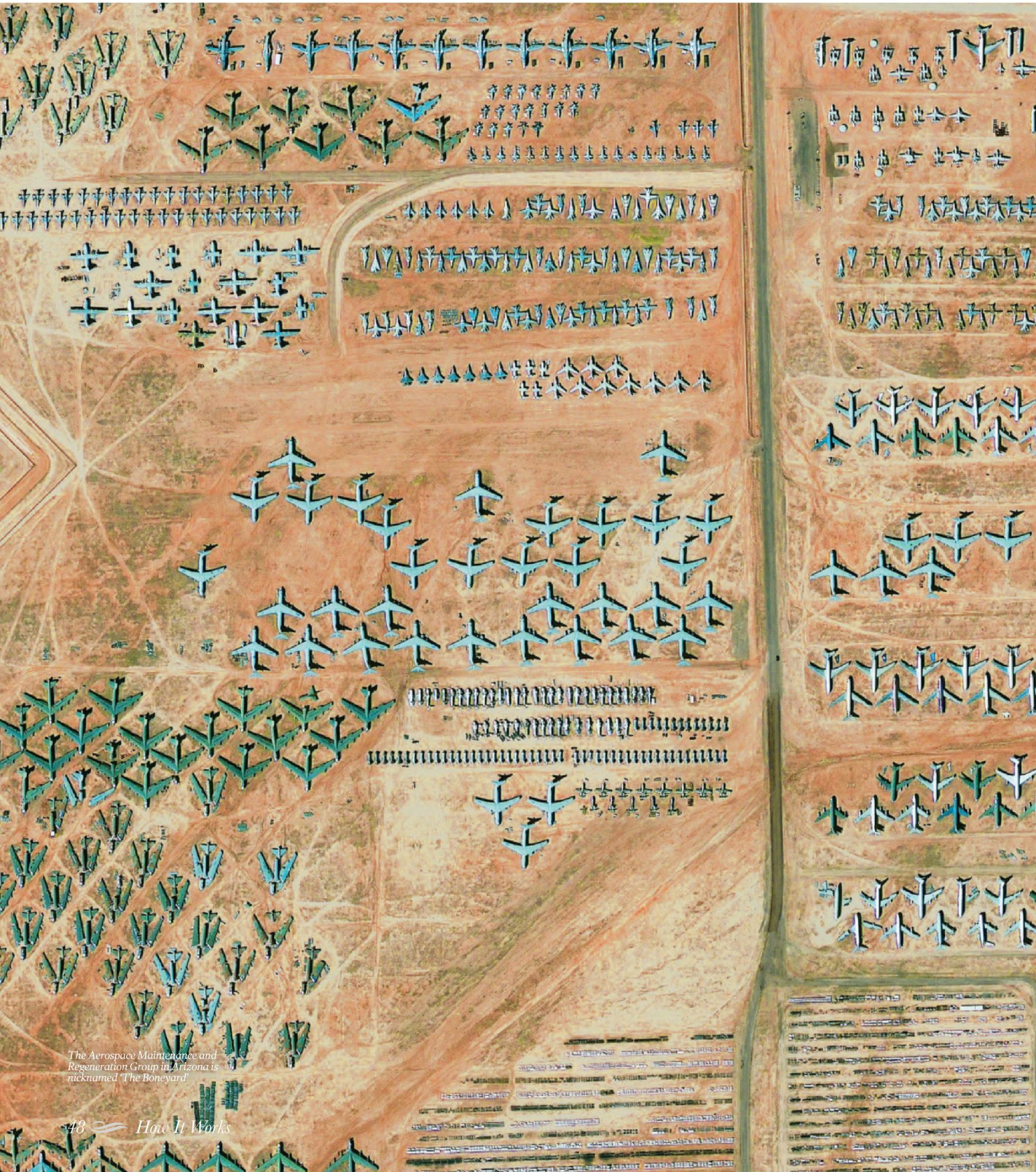
The paint will glow different colours to alert the driver to road temperatures so they can respond accordingly

The world's infrastructure is constantly being improved and updated to accommodate the ever-increasing amount of traffic on the roads. One of these developments is the use of glow-in-the-dark lining on the highway contours.

The brainchild of designer and innovator Daan Roosegaarde and Dutch company Heijmans, it is part of a development known as Smart Highway and will strive to improve road safety and travel efficiency. Using a photoluminescent powder, the invention would lessen the need for street lighting, which will save vast amounts on energy and material costs and also lessen light pollution. The powder is charged during the day by solar energy and will provide ten hours of light on one charge.

Another invention is dynamic paint. Instead of night lighting, the paint is based around temperature fluctuations. So when the climate plunges into sub-zero conditions or undergoes a heat wave, the paint will show drivers the potential hazards that lay ahead.

© Studio Roosegaarde & Heijmans; BAE Systems; Studio Roosegaarde and Heijmans



The Aerospace Maintenance and Regeneration Group in Arizona is nicknamed 'The Boneyard'

What are plane graveyards?

Where do old aircrafts go to retire and how do they help provide for the next generation of aeroplanes?

The advent of Google Earth has allowed for many stunning images of the planet on which we live, but few have caused such a reaction as the sites of plane graveyards, scattered across the world.

As various commercial and military aircraft are damaged or retired, they are sent to vast expanses of land for safe keeping or to have their parts repurposed into new aircraft.

One of the most jaw-dropping examples of these sites is the Aerospace Maintenance and Regeneration Group (AMARG) in Tucson, Arizona. This sprawling 10.5-square-kilometre (four-square-mile) US airbase houses more than 4,000 retired aircraft, including the B-52 Stratofortress, B-1B Lancer bomber and the A-10 Thunderbolt. Another such site is the Mojave Air & Space Port, which is the final resting place for hundreds of former commercial liners.

These facilities are essential for the safe post-retirement care of thousands of aircraft, many of which contain valuable hardware and – since many are warplanes – military tech that could be dangerous in the wrong hands.

Wherever possible, these planes have their working parts harvested for use on newer aircraft, but looking down from straight above at thousands of massive sky vehicles grounded for life is an incredible sight, if a slightly heart-wrenching one.

Tours are available for some aircraft graveyards, such as the AMARG, giving aircraft enthusiasts one last opportunity to see a potted history of aviation, dating back to WWII.

© SPL; Rex Features; Thinkstock

Lasham Airfield in Hampshire, UK, hosts 26 aeroplanes from now-defunct budget airlines

What's inside the ultimate RV?

This camper van has everything you need for an adventure

Most fathers want to show their children the world, but American inventor Bran Ferren took that dream a step further. He designed his camper van with an office, kitchen and bedroom, and even a pop-up tent on the roof for his four-year-old daughter Kira, who the KiraVan is named after.

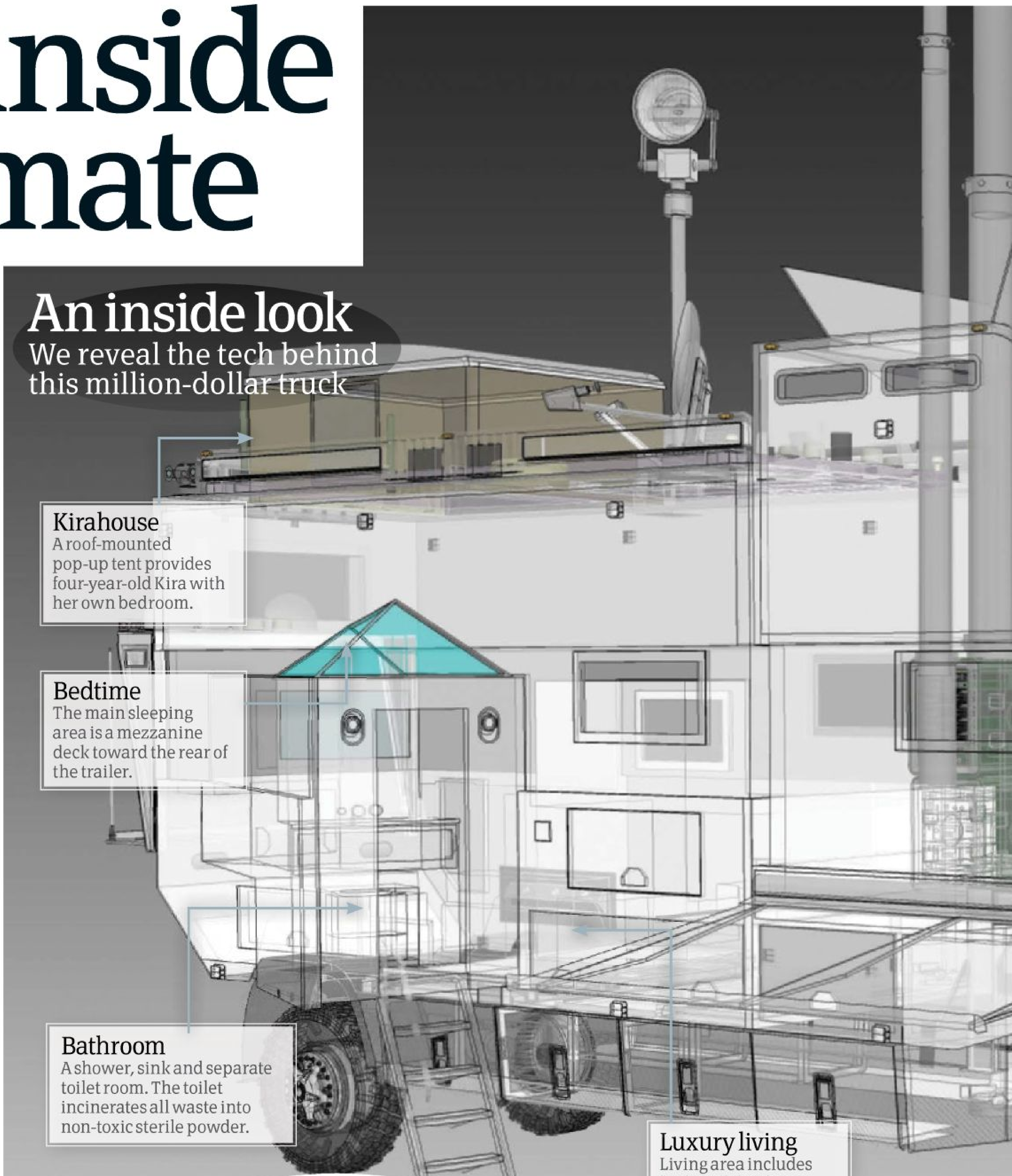
It can travel 2,000 miles without resupply, powered by a modified Mercedes-Benz Unimog chassis, renowned for their reliability and cross-country performance. The diesel engine has been fitted with sensors to monitor temperature, vibration and torque so the driver has a constant picture of how the engine is performing. A heated fuel tank ensures the diesel won't freeze in low temperatures and also filters the diesel so only clean, pure fuel is fed to the engine for optimum performance.

It's comfortable for the driver too, thanks to a vibration-reducing chair. The cockpit is surrounded by screens that display road conditions, GPS mapping and weather details. Drones even fly ahead to check on traffic. At 15.8 metres (52 feet) long and over three metres (10 feet) high, the KiraVan uses a tractor-trailer design like an articulated lorry. This gives the trailer off-roading capability by adding a hydrostatic drive system, enabling six-wheel drive at speeds up to 40km/h (25mph). Hydrostatic drives use pressurised fluid to drive a motor, negating the need for a drive shaft, which would restrict movement between the two units.

The insulated trailer unit has a bedroom, office, kitchen, living quarters and an eco-friendly bathroom. Slide-out compartments and a motorised rising roof section doubles the internal living space when deployed. You'll find home comforts such as a media library, flat-screen TV and seating area, and enough supplies for to last three people three weeks before having to restock.

An inside look

We reveal the tech behind this million-dollar truck

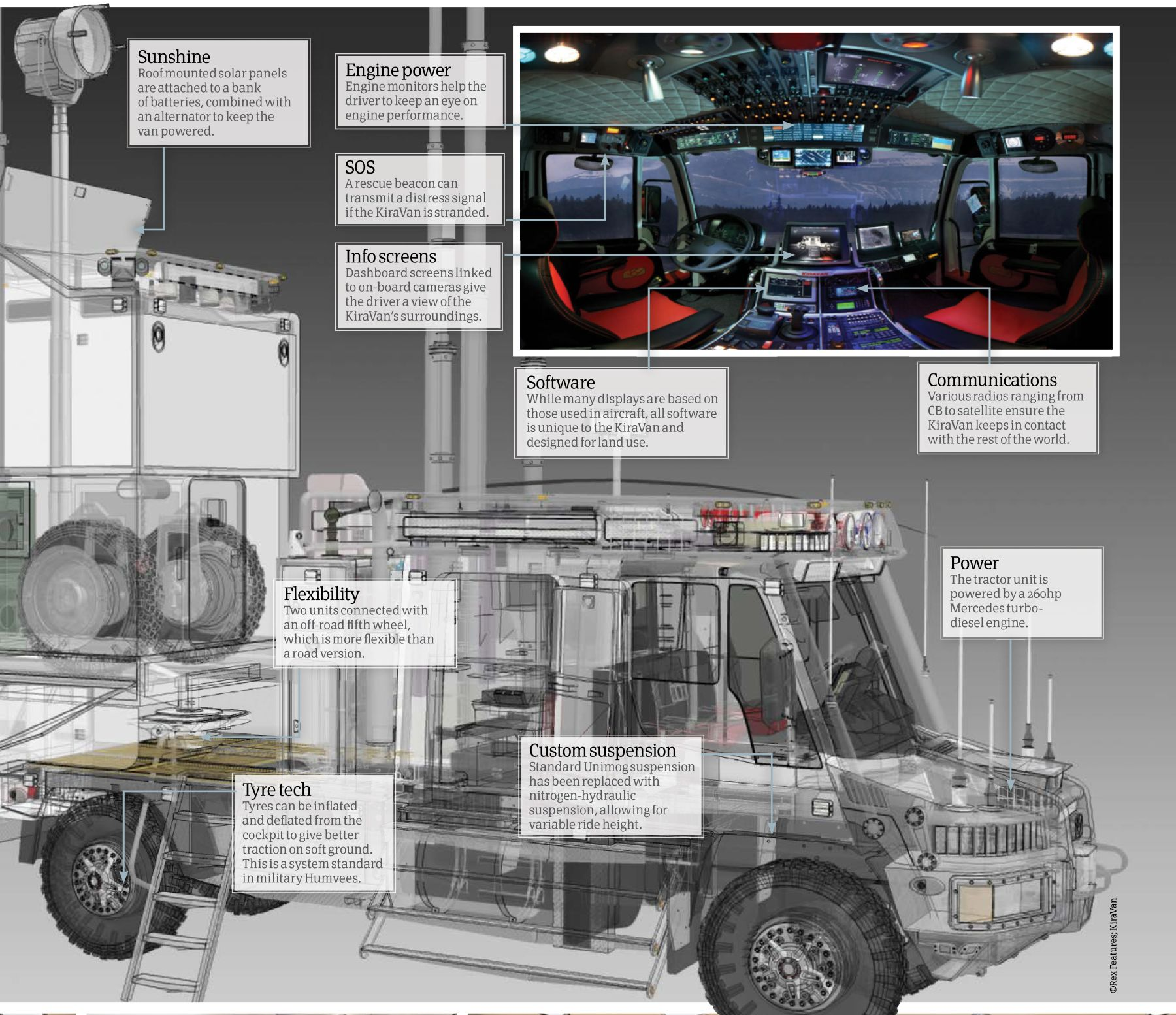


Kirahouse
A roof-mounted pop-up tent provides four-year-old Kira with her own bedroom.

Bedtime
The main sleeping area is a mezzanine deck toward the rear of the trailer.

Bathroom
A shower, sink and separate toilet room. The toilet incinerates all waste into non-toxic sterile powder.

Luxury living
Living area includes high-tech kitchen, seating area and a media library with a satellite HDTV.



Sunshine
Roof mounted solar panels are attached to a bank of batteries, combined with an alternator to keep the van powered.

Engine power
Engine monitors help the driver to keep an eye on engine performance.

SOS
A rescue beacon can transmit a distress signal if the KiraVan is stranded.

Info screens
Dashboard screens linked to on-board cameras give the driver a view of the KiraVan's surroundings.

Software
While many displays are based on those used in aircraft, all software is unique to the KiraVan and designed for land use.

Communications
Various radios ranging from CB to satellite ensure the KiraVan keeps in contact with the rest of the world.

Flexibility
Two units connected with an off-road fifth wheel, which is more flexible than a road version.

Power
The tractor unit is powered by a 260hp Mercedes turbo-diesel engine.

Custom suspension
Standard Unimog suspension has been replaced with nitrogen-hydraulic suspension, allowing for variable ride height.

Tyre tech
Tyres can be inflated and deflated from the cockpit to give better traction on soft ground. This is a system standard in military Humvees.

©Rex Features; KiraVan

How do solar-powered aircraft fly?

The flying machines that are fuelled only by the Sun

As the search for renewable and carbon-neutral forms of energy intensifies, solar energy is leading the way in fuelling the next generation of aircraft.

One aircraft breaking boundaries in this area is the Solar Impulse 2. This incredible machine is set to launch a non-stop, round-the-world trip powered only by the Sun. It will do this by using 72-metre (236-foot) wide wings, each of which will be carrying over 8,500 solar cells, powering four electric motors and four lithium batteries. Despite this astonishing wingspan, the entire aircraft will only weigh 2,300 kilograms (5,071 pounds), about as heavy as a large great white shark.

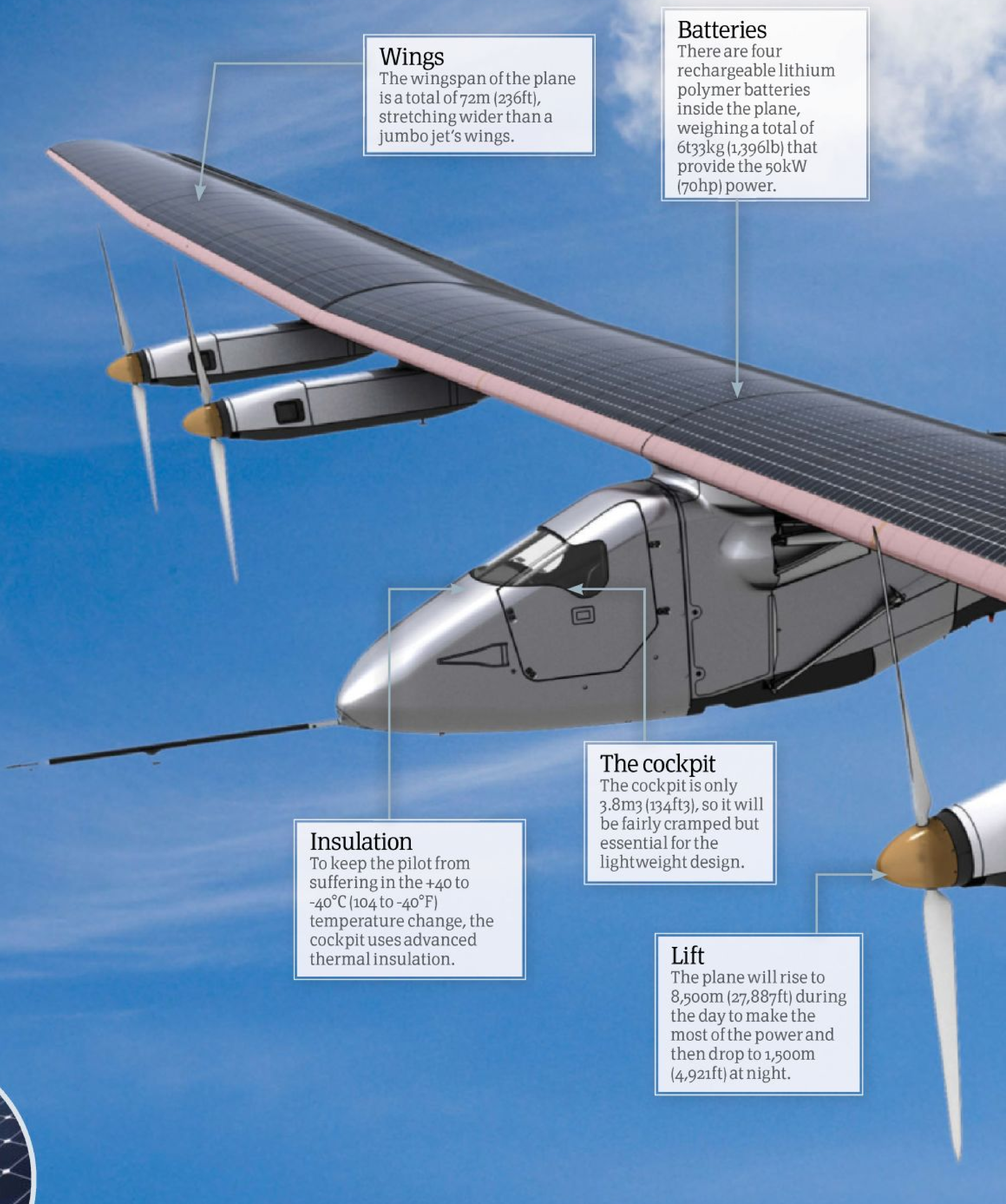
Another major player in the world of solar powered aviation is Solar Flight. Their newest project is Sunseeker Duo, which is the only two-seater solar-powered aeroplane in operation. It follows a similar pattern to the Solar Impulse 2, with long wings covered with solar panels and a lightweight body. Its panels have been improved to become 50 per cent more efficient than their predecessors. It can fly for 12 hours and its engine produces 25 kilowatts (33.5 horsepower) of power.

The main question with using solar power is 'what happens at night?' During the day, not all the energy is used. Enough will be stored in the batteries to allow the aircraft fly at night.

The next challenge for solar-powered aviation is to be able to carry multiple passengers.

How solar panels work

We have heard a lot about solar panels converting sunlight to energy, but how does that process actually work? Inside a solar panel is a number of silicon cells, placed on top of each other. One of the silicon atoms has all its electrons, while the one beneath it has a few missing. In order to restore the balance, the full silicon atom transfers electrons to the one below, but it needs light to trigger the process. Once the sunlight hits the panel, electrons are transferred from one silicon cell to the other, thus creating an electric current.



Wings
The wingspan of the plane is a total of 72m (236ft), stretching wider than a jumbo jet's wings.

Batteries
There are four rechargeable lithium polymer batteries inside the plane, weighing a total of 633kg (1,396lb) that provide the 50kW (70hp) power.

Insulation
To keep the pilot from suffering in the +40 to -40°C (104 to -40°F) temperature change, the cockpit uses advanced thermal insulation.

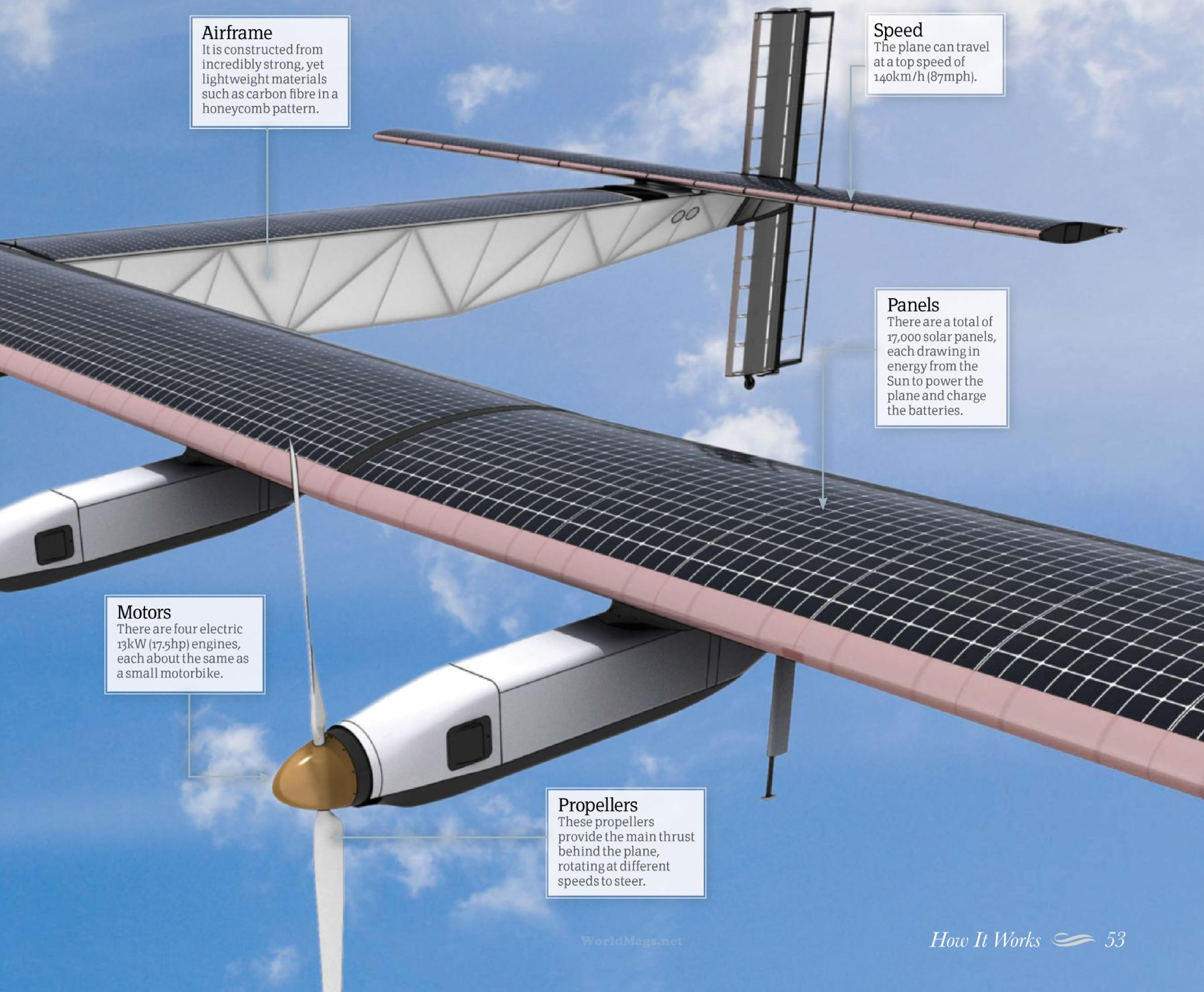
The cockpit
The cockpit is only 3.8m3 (134ft3), so it will be fairly cramped but essential for the lightweight design.

Lift
The plane will rise to 8,500m (27,887ft) during the day to make the most of the power and then drop to 1,500m (4,921ft) at night.

Despite the massive wingspan, the Solar Impulse weighs about the same as two small cars

Close up power

ESA's Solar Orbiter will be getting a ridiculous boost of solar energy when it takes off in 2017 as its mission is to get closer to the Sun than any probe has before, in order to take incredible pictures of the star. With its 3.1-metre x 2.4-metre (10.2-foot x 7.9-foot) sunshield, this craft will travel just 42 million kilometres (26 million miles) away from the Sun to take high-resolution images and perform experiments. It has been rigorously tested, as it will experience temperatures ranging from 520 degrees Celsius (968 degrees Fahrenheit) to -170 degrees Celsius (-274 degrees Fahrenheit). Its aim is to help scientists lean more about the inner heliosphere and how solar activity affects it, answering questions about solar winds, coronal magnetic fields and solar eruptions.



Airframe
It is constructed from incredibly strong, yet lightweight materials such as carbon fibre in a honeycomb pattern.

Speed
The plane can travel at a top speed of 140km/h (87mph).

Panels
There are a total of 17,000 solar panels, each drawing in energy from the Sun to power the plane and charge the batteries.

Motors
There are four electric 13kW (17.5hp) engines, each about the same as a small motorbike.

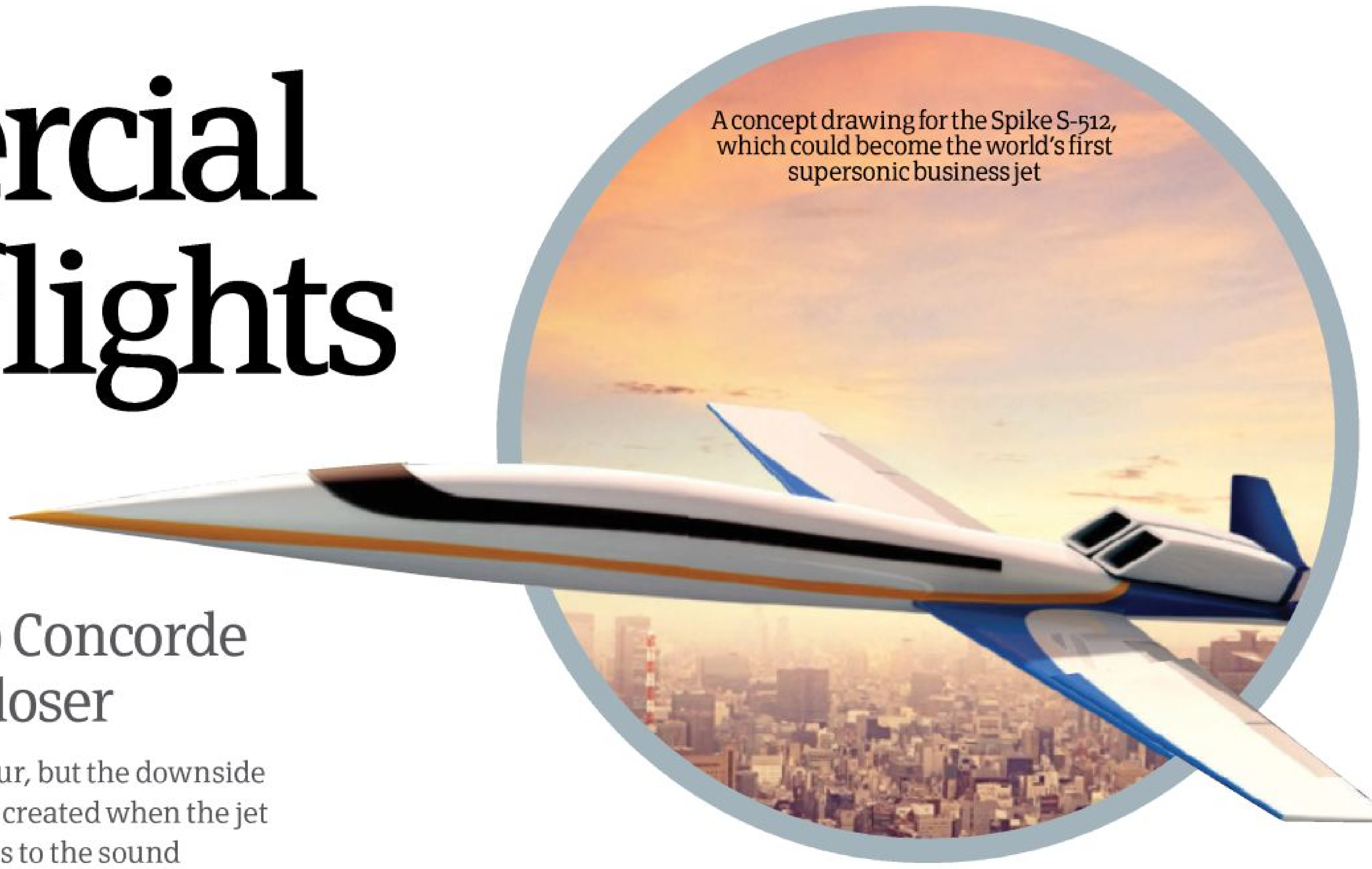
Propellers
These propellers provide the main thrust behind the plane, rotating at different speeds to steer.

Will commercial supersonic flights be possible again?

The heir to Concorde is getting closer

From its debut in 1969 until it touched down for the last time in 2003, Concorde broke all kinds of records, as well as the sound barrier nearly 50,000 times. The world's first and only commercial supersonic jet could cross the Atlantic in about three hours due to its sleek body and revolutionary engines. They used reheat technology that added extra fuel at the final stage of the engine cycle to make it reach speeds of 1,350 miles per hour, but the downside was the sonic boom created when the jet pushed sound waves to the sound barrier, which then became shock waves that disturbed people living below.

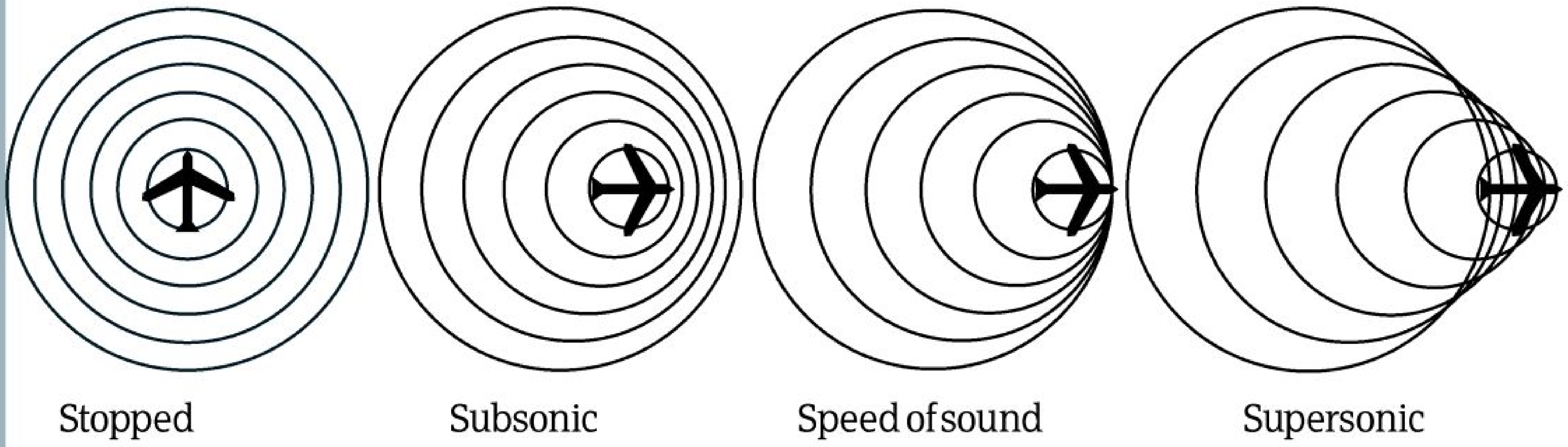
The next generation looks to reduce this noise by making the nose longer and thinner, meaning fewer shock waves are created. It is hoped that supersonic aircraft from Boeing and Lockheed Martin could be ready by 2030.


A concept drawing for the Spike S-512, which could become the world's first supersonic business jet

> "The world's first and only commercial supersonic jet could cross the Atlantic in about three hours"

How a sonic boom is created

As an aircraft travels, it compresses the air in front of it. These waves move away from the aircraft at the speed of sound, but the faster the plane flies, the more the waves pile on top of one another. If a plane travels at supersonic speeds, all of the sound waves that would have travelled ahead of the plane get released in one go. This is why we hear such a loud boom when the sound barrier is broken.

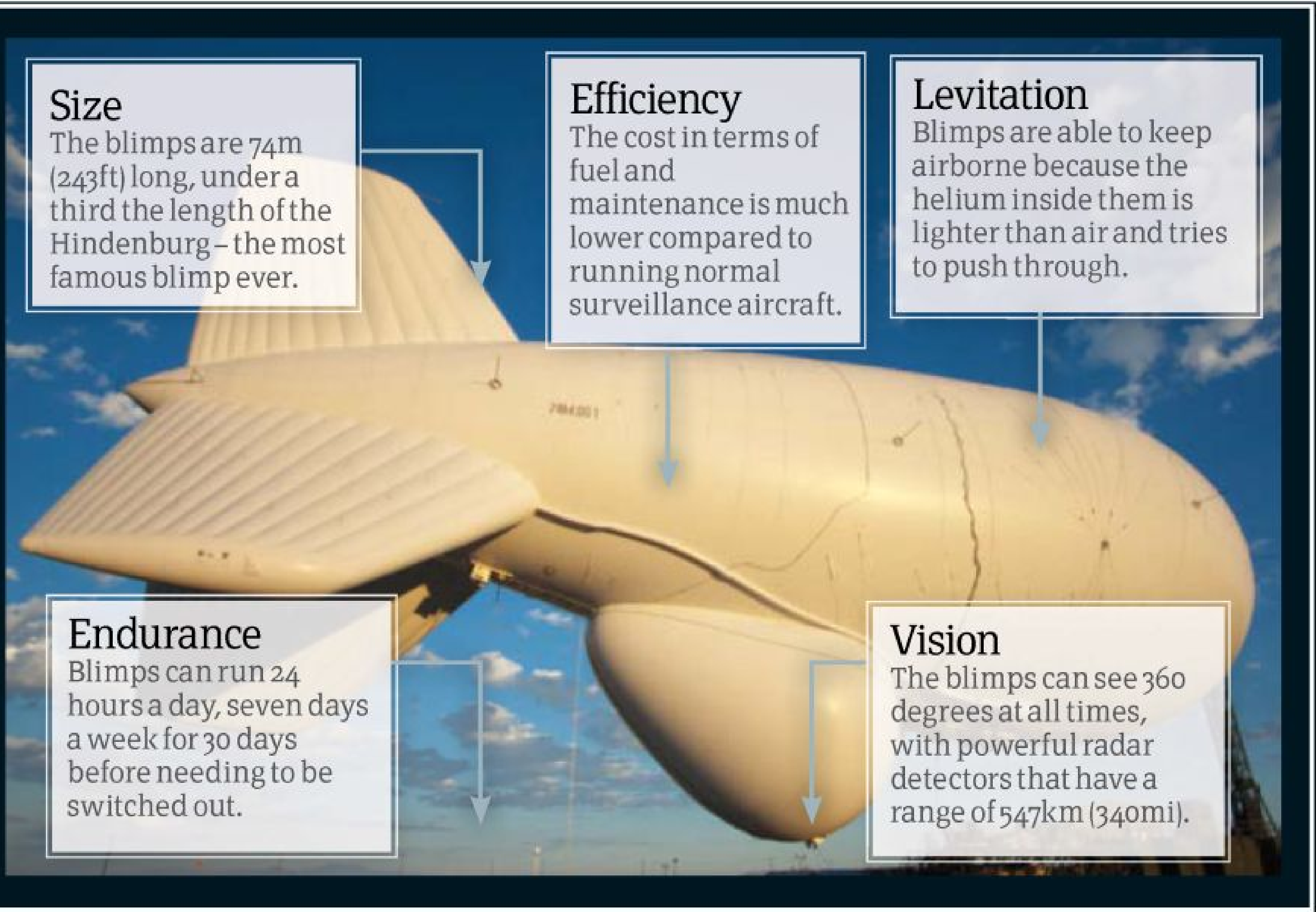


Are blimps back?

The wartime aerial giants are back to protect our skies

Blimps were originally designed as an aircraft that could take passengers across the Atlantic in style and comfort. Filled with lighter-than-air helium, they became a fixture over the skies in wartime Britain as barrage balloons protected the country from enemy warplanes flying over major cities in WWI.

While the 1937 Hindenburg disaster put an end to their role as commercial aircraft, they have made a return in the pursuit of national defence. A new breed of blimps is being used for relatively cheap 360-degree, 24/7 defence surveillance over a range of military bases in the United States. Raytheon's JLENS system includes 74-metre long aircrafts which float 3,048 metres (above the ground and can see 547 kilometres away.


Size
The blimps are 74m (243ft) long, under a third the length of the Hindenburg – the most famous blimp ever.

Efficiency
The cost in terms of fuel and maintenance is much lower compared to running normal surveillance aircraft.

Levitation
Blimps are able to keep airborne because the helium inside them is lighter than air and tries to push through.

Endurance
Blimps can run 24 hours a day, seven days a week for 30 days before needing to be switched out.

Vision
The blimps can see 360 degrees at all times, with powerful radar detectors that have a range of 547km (340mi).

© Spike Aerospace; Raytheon Company

How does the Smart Rearview Mirror work?

Nissan's innovative technology leads the way when it comes to looking backward

One of the most important safety aspects to a vehicle is the ability to provide good all-around vision to its driver. A huge glass windscreen means looking forward isn't an issue, but being able to see down the side and out the back of a vehicle is slightly trickier. For decades, vehicles have employed a variety of mirrors to combat this, with external wing mirrors and an interior rear-view mirror not just commonplace but also required by law in most countries. However, mirrors create blind spots, which can lead to danger as a driver cannot see certain points around a vehicle. Using live camera feeds and screens instead of mirrors is now becoming a viable solution to this age-old problem.

Early in 2014, Japanese automotive manufacturer Nissan debuted its variation of this technology, named Smart Rearview Mirror, at the New York Motor show on its Rogue model.

The Smart Rearview Mirror works by a small camera, mounted in the rear window of a vehicle, projecting live to the driver via an LCD monitor mounted within the frame of a traditional rear-view mirror. The driver is afforded a better view of the environment behind the vehicle, minimising blind spots – and as the camera is mounted at the rear of the car, the driver doesn't have to look past the interior and C pillars of their own vehicle to the world outside.

What's more, the technology is switchable, so drivers can choose whether they'd like to use the camera and LCD monitor or the traditional mirror method when viewing the environment at the rear of a vehicle, with the simple press of a button.

The safety revolution will be televised

The Smart Rearview Mirror from Nissan is the latest innovation in a long line of technologies instilled in an automobile to improve its overall safety, with many features designed to work effectively in tandem with others.

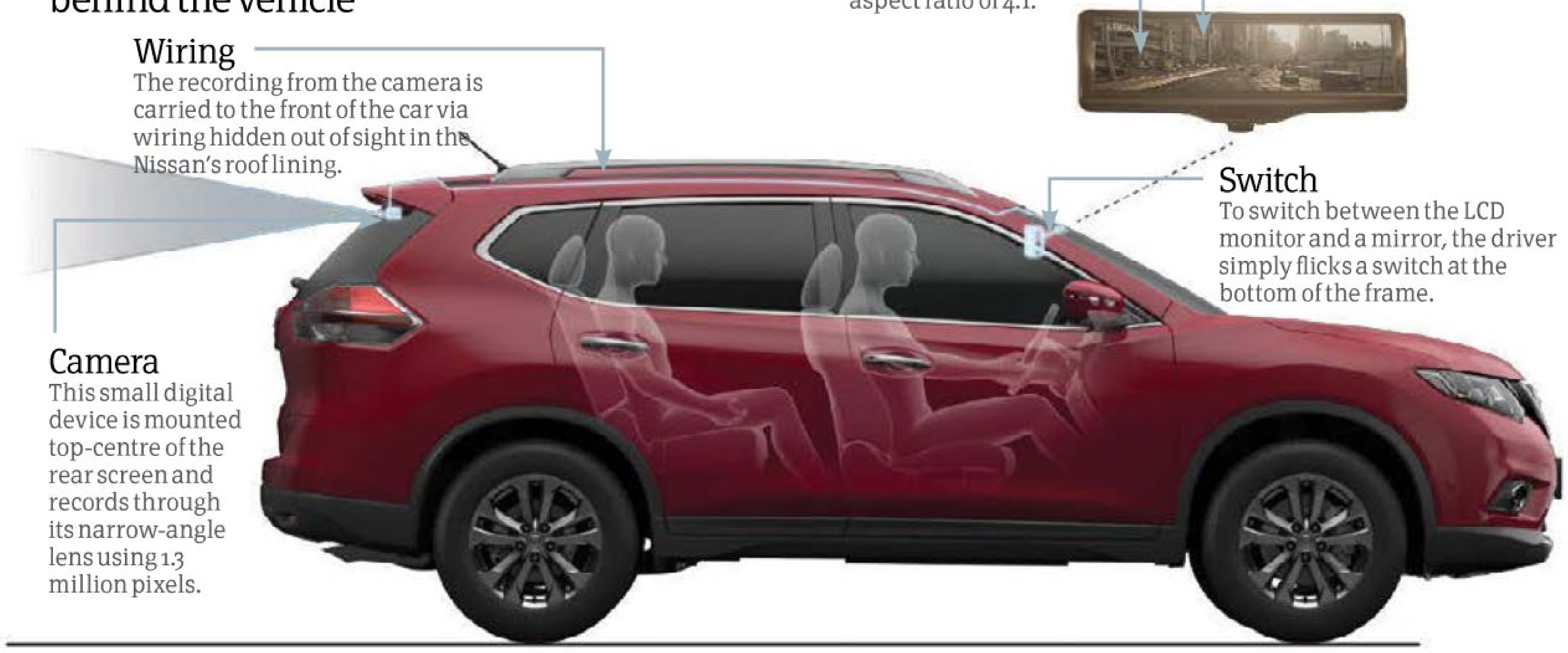
With Nissan, the Rogue has many such features, including Around View Monitor, which stitches together images from four different cameras to produce an all-encompassing, top-down view from the rear of the car, which is invaluable when spotting smaller hazards such as bollards or running children when reverse parking in town.

Another great Nissan feature is Moving Object Detection, which provides an audible warning when another object moves while the car is reversing, helping to avoid a rear-end smash.

All of these safety features work in tandem to reduce the risk of driver error behind the wheel, in this case by providing greater vision at the rear of the vehicle.

The Smart Rearview Mirror in action

Here's how Nissan's innovative tech will help inform the driver of what's happening behind the vehicle



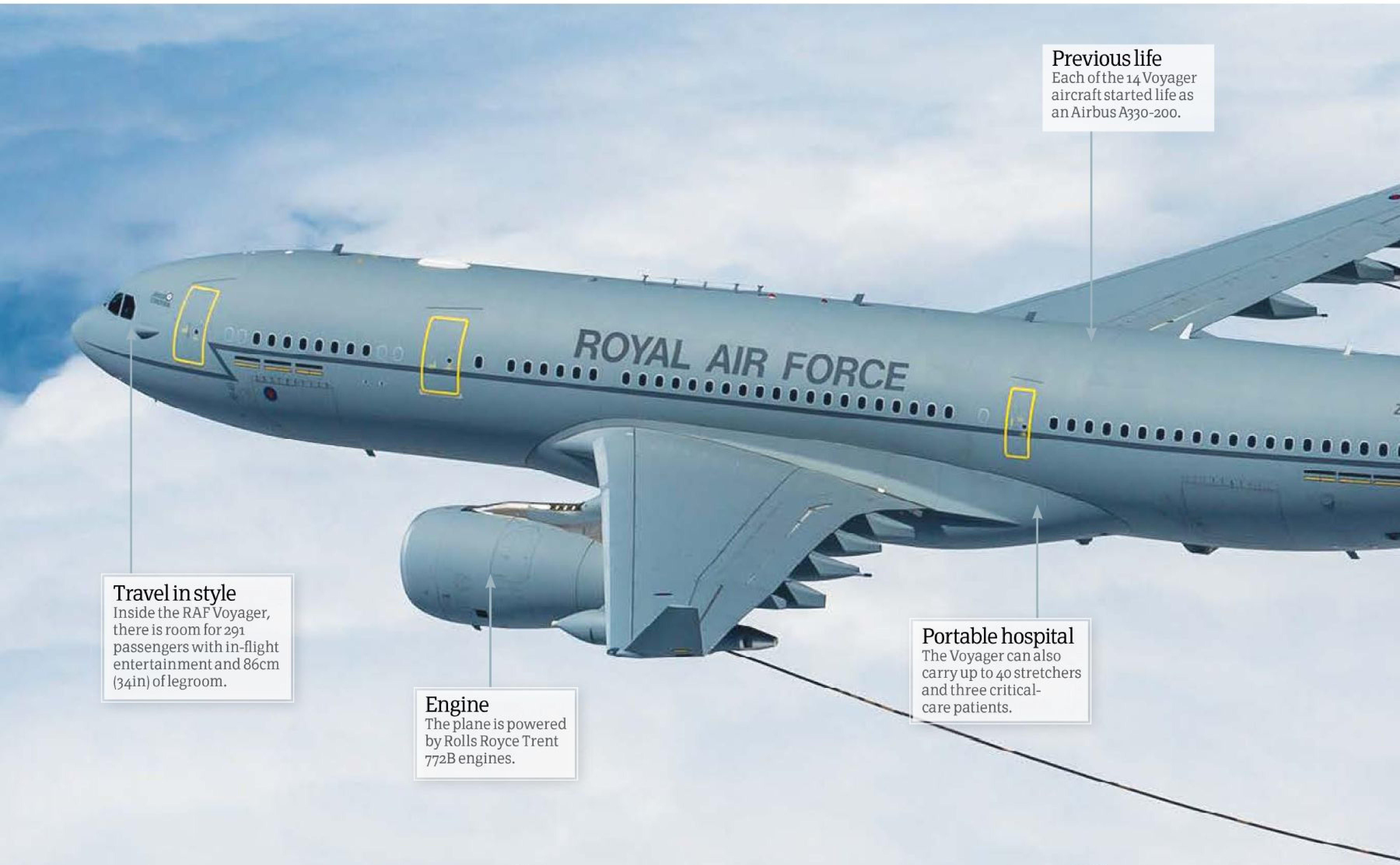
Wiring
The recording from the camera is carried to the front of the car via wiring hidden out of sight in the Nissan's roof lining.

LCD monitor
The recording from the camera is displayed live on the LCD monitor with a unique aspect ratio of 4:1.

Mirror
Mounted in front of the monitor in the frame is a conventional mirror. If the driver would rather use this when viewing the environment behind the car, they can turn the monitor off.

Switch
To switch between the LCD monitor and a mirror, the driver simply flicks a switch at the bottom of the frame.

Camera
This small digital device is mounted top-centre of the rear screen and records through its narrow-angle lens using 1.3 million pixels.



Previous life
Each of the 14 Voyager aircraft started life as an Airbus A330-200.

Travel in style
Inside the RAF Voyager, there is room for 291 passengers with in-flight entertainment and 86cm (34in) of legroom.

Engine
The plane is powered by Rolls Royce Trent 772B engines.

Portable hospital
The Voyager can also carry up to 40 stretchers and three critical-care patients.

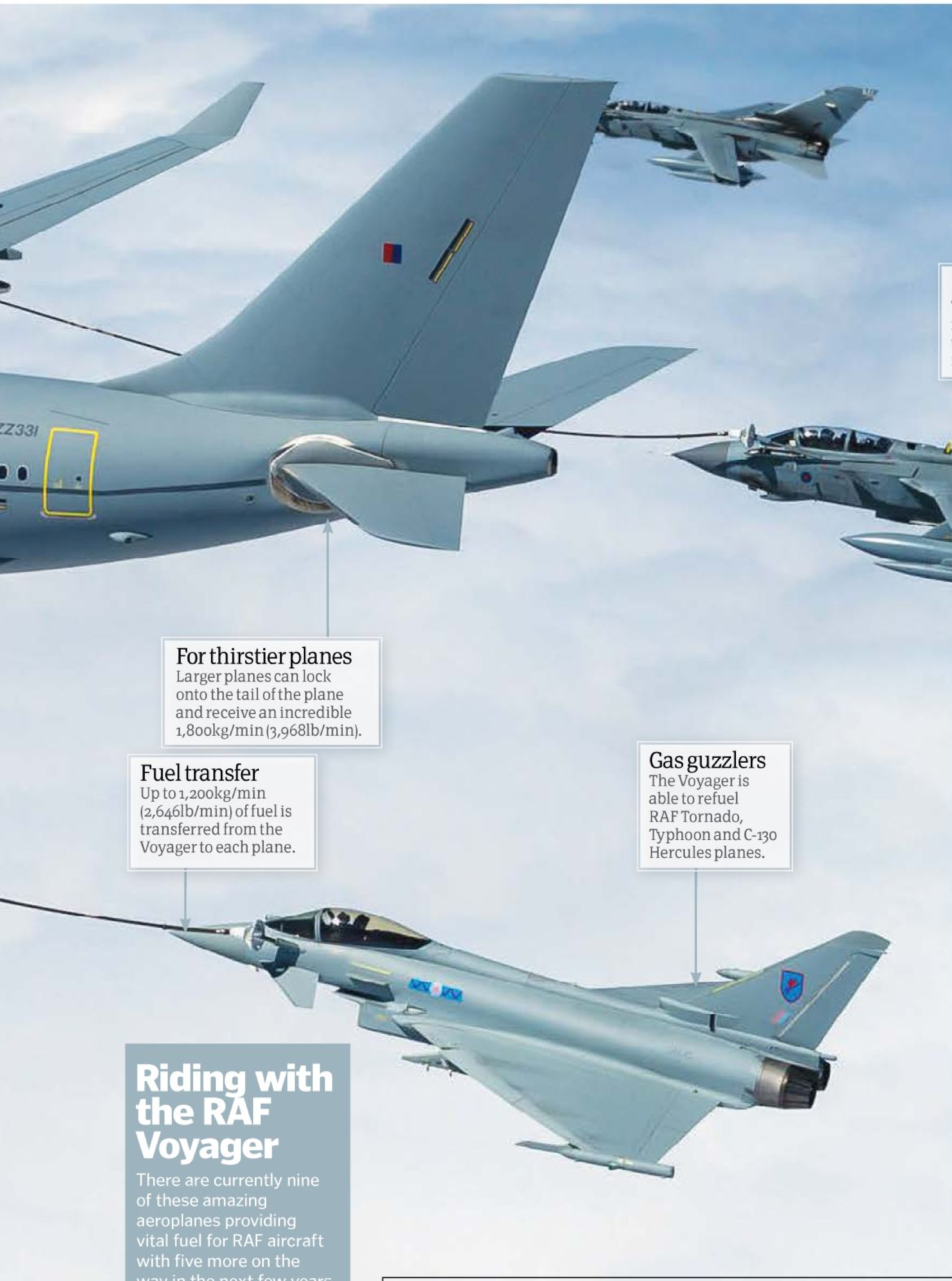
Can planes refuel in mid-air?

How planes are able to keep flying for days thanks to airborne petrol pumps

You might think that filling your car up at the petrol station is a bit of a tiresome task, fiddling around with the fuel cap and trying to squeeze the pump so you reach a nice round number. Imagine doing that thousands of metres in the air, travelling at hundreds of kilometres an hour.

This is the task that faces every pilot that flies a plane like the RAF Voyager, an aircraft designed to refuel planes while still in the air. This huge aircraft lines up with other planes, which lock onto it via fuel hoses and receive up to 1,200 kilograms (2,646 pounds) per minute of fuel from the pods underneath each wing. This is really useful as it means surveillance aircraft are able to remain in the air for much longer periods of time, so they don't lose targets or give away crucial secrets – like where their base is – by repeatedly returning there to refuel.

Another benefit is that fighter planes can lift off with less fuel than usual and more weaponry, because the refuelling plane can follow them and deliver fuel when needed. This makes long-distance missions much more practical and worthwhile. Each aerial refuelling has to be executed with pinpoint precision, with highly skilled pilots manoeuvring themselves into position while still going at huge speeds.



Doubling up
Two planes can be refuelled at the same time, as hoses drop from each wing.

For thirstier planes
Larger planes can lock onto the tail of the plane and receive an incredible 1,800kg/min (3,968lb/min).

Fuel transfer
Up to 1,200kg/min (2,646lb/min) of fuel is transferred from the Voyager to each plane.

Gas guzzlers
The Voyager is able to refuel RAF Tornado, Typhoon and C-130 Hercules planes.

Riding with the RAF Voyager

There are currently nine of these amazing aeroplanes providing vital fuel for RAF aircraft with five more on the way in the next few years. Each Voyager is capable of carrying an incredible 111 tonnes of fuel and 43 tonnes of freight in its cargo hold. This means it can respond to most calls from a great distance away as it has both the fuel range and ability to hold supplies for long journeys.

Magnificent robots in their flying machines

NASA is also active in the field of aerial refuelling, leading the research into autonomous refuelling, which is where unmanned aircraft can receive fuel from another unmanned tanker.

The aircraft they are using for these experiments are Global Hawks, one of which has been specially prepared to receive fuel and the other to provide it. They line up with one another, before the lead aircraft drops the hose down to the following aircraft, which detects the hose's position and locks onto the drogue, which is a funnel on the end of the hose.

How to refuel a plane

Lower the hoses

A 27.4m (90ft) hose is stored in each wing. At the command from the mission system operator (MSO), they are released and unwind through an opening in the wing. Each hose has a basket on the end that will be caught by the following plane.

Locking on

The aircraft to be refuelled extends a probe and flies toward the hose so the probe enters the basket. Once this connection has been made, the MSO is able to give the order for the refuelling to begin. Once finished, it slows down and the hose disconnects.

How do four-stroke engines work?

Learn about the four simple steps used to generate power and get our vehicles moving

Put simply, four-stroke engines generate power by initiating controlled explosions that provide movement. In the case of a motor vehicle, most of which use four-stroke engines, these controlled explosions produce kinetic energy to turn the wheels, propelling the vehicle.

The explosions are initiated by igniting, combusting and expanding a fuel and air mixture during a four-step process: intake, compression, power and exhaust (or more commonly 'suck, squeeze, bang, blow').

The four-stroke engine (sometimes called the Otto cycle engine) was invented in 1876 when Nikolaus Otto built the first practical iteration of the design and fitted it to a motorcycle. This was seen as the first major alternative to the contemporary steam engine, and the engineering concept has undergone many evolutions since, incorporating different fuels and even combining with other energy sources in hybrid vehicles, such as hydrogen.

Today, four-stroke engines are still the most common type of internal combustion engine used for transport as they offer a smooth ride, produce less pollution than many alternatives and are much more efficient and powerful than a two-stroke or rotary engine. Going against them however, four-stroke engines can be complicated to manufacture and repair in the event of malfunction, as there are so many components that go in to the system. ✱

Engine efficiency in focus

Engine efficiency is the transfer of readily available energy from a fuel into usable power output from an engine consuming that fuel. Engine efficiency is measured by dividing the output energy by the heat lost. Most petrol internal combustion engines actually have a low efficiency – usually in the region of 20-25 per cent.

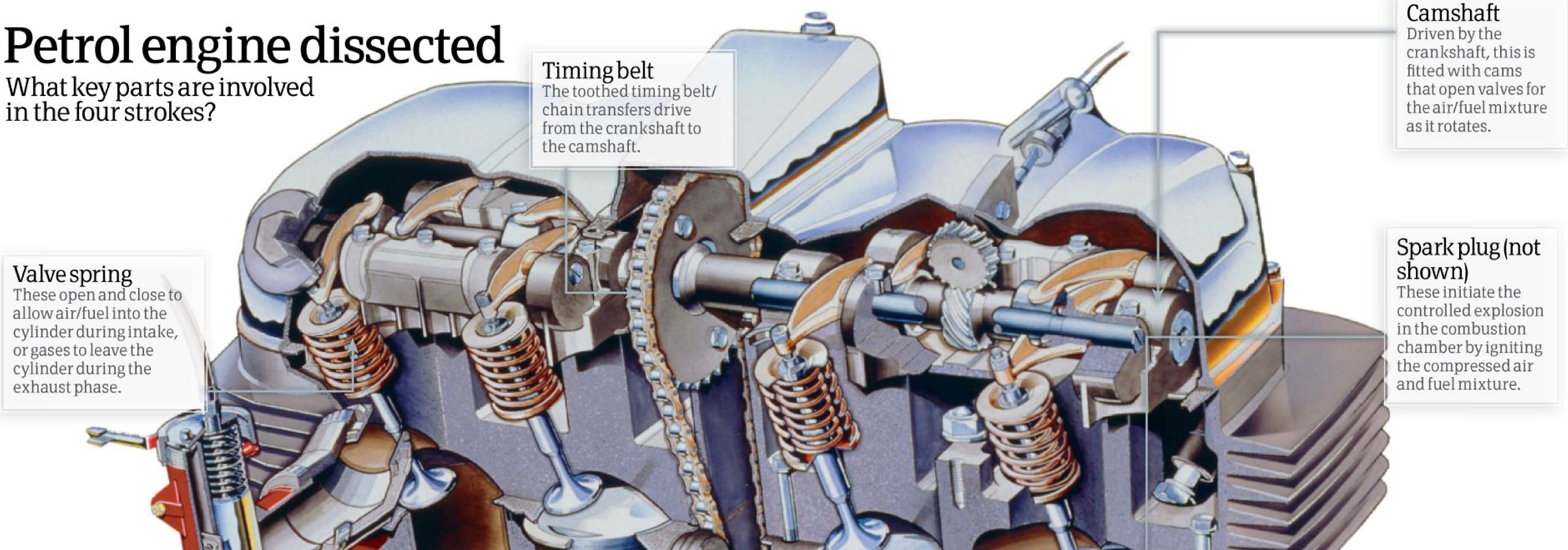
The better the efficiency, the lower the fuel consumption, reducing emissions. This also makes for a reduction in taxes as pollutant output has been cut.

Key factors that dictate engine efficiency are heat and friction. As a result, engines use a variety of components to try and counter these problems. For example, oil is used to help reduce the friction between moving parts in an engine, while a radiator helps to keep the water running through an engine cool. Vehicles also have a cooling fan for the engine compartment, which is activated when operating temperatures become too hot.

As technology has evolved, engine efficiency has improved. For example, turbocharged engines utilise a front-mounted intercooler to keep heat down while driving.

Petrol engine dissected

What key parts are involved in the four strokes?

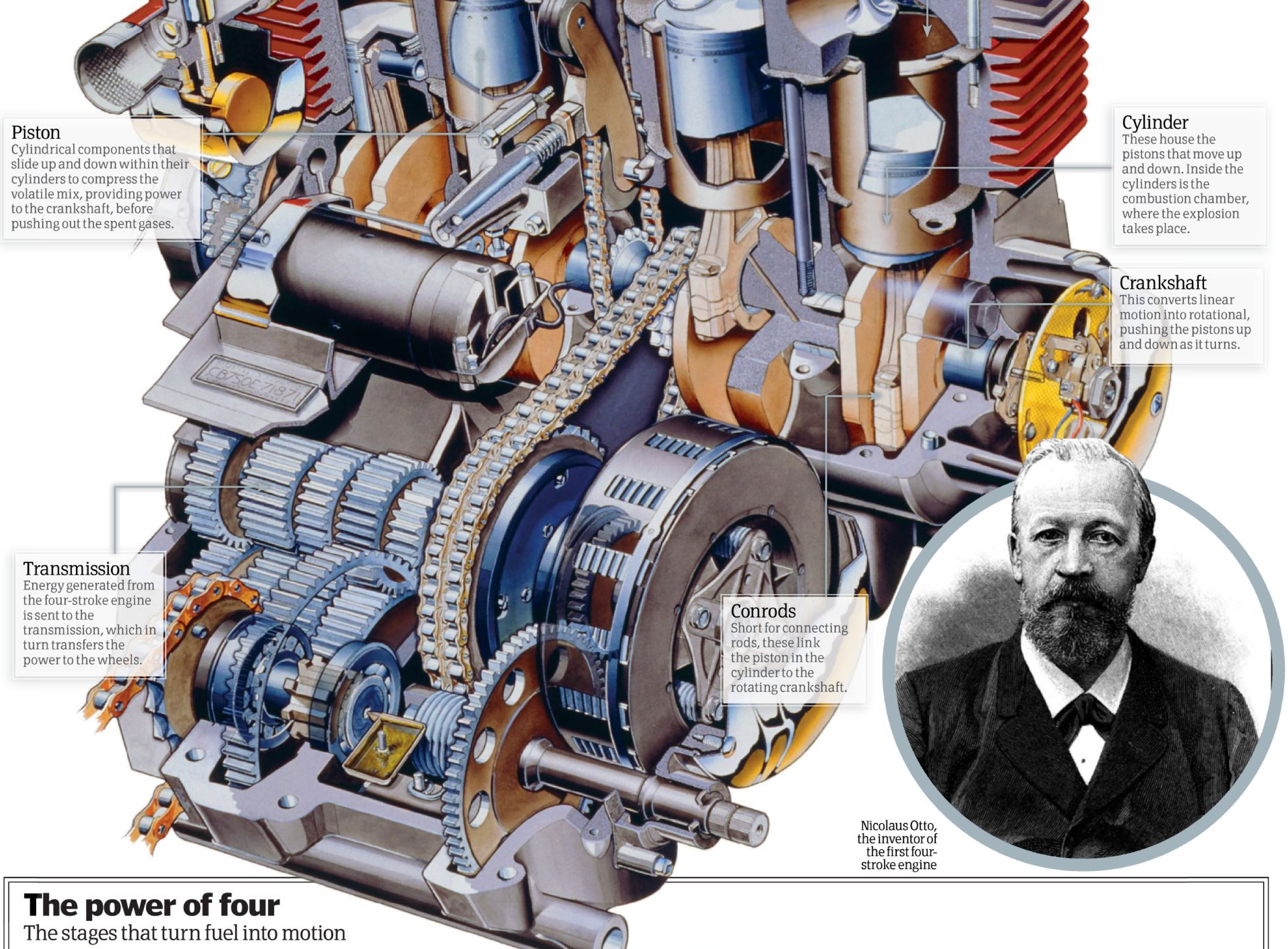


Timing belt
The toothed timing belt/chain transfers drive from the crankshaft to the camshaft.

Camshaft
Driven by the crankshaft, this is fitted with cams that open valves for the air/fuel mixture as it rotates.

Valve spring
These open and close to allow air/fuel into the cylinder during intake, or gases to leave the cylinder during the exhaust phase.

Spark plug (not shown)
These initiate the controlled explosion in the combustion chamber by igniting the compressed air and fuel mixture.



Piston
Cylindrical components that slide up and down within their cylinders to compress the volatile mix, providing power to the crankshaft, before pushing out the spent gases.

Cylinder
These house the pistons that move up and down. Inside the cylinders is the combustion chamber, where the explosion takes place.

Crankshaft
This converts linear motion into rotational, pushing the pistons up and down as it turns.

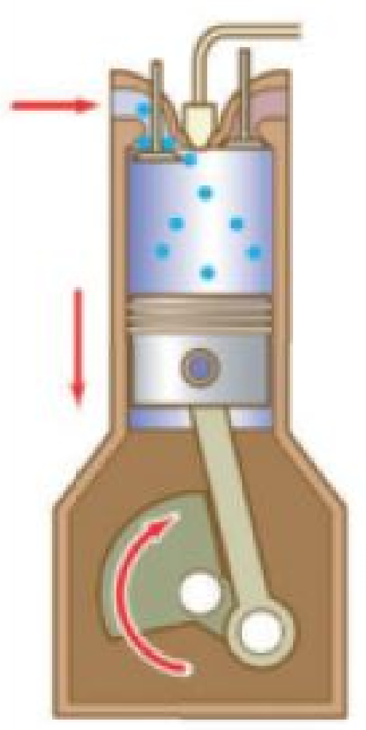
Transmission
Energy generated from the four-stroke engine is sent to the transmission, which in turn transfers the power to the wheels.

Conrods
Short for connecting rods, these link the piston in the cylinder to the rotating crankshaft.

Nicolaus Otto, the inventor of the first four-stroke engine

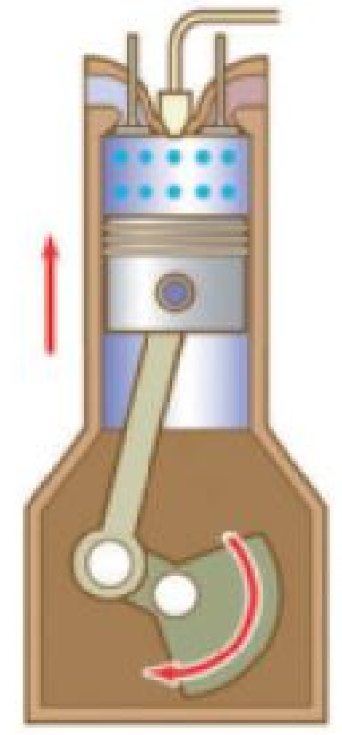
The power of four

The stages that turn fuel into motion



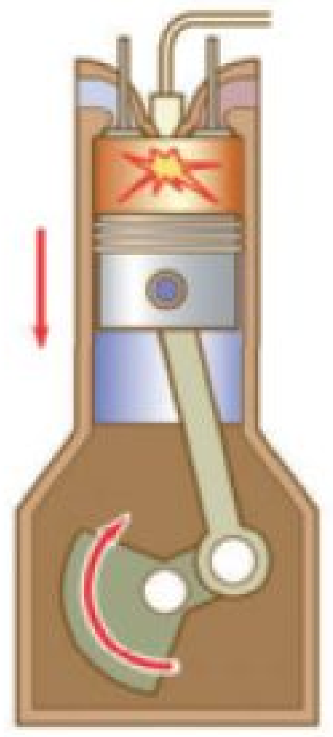
1. Intake

As the crankshaft turns and the piston moves down the cylinder, the fuel/air mixture is drawn in through the inlet valve (top left). When the piston has reached the bottom, the cylinder is filled with the fuel/air mixture, and the inlet valve closes.



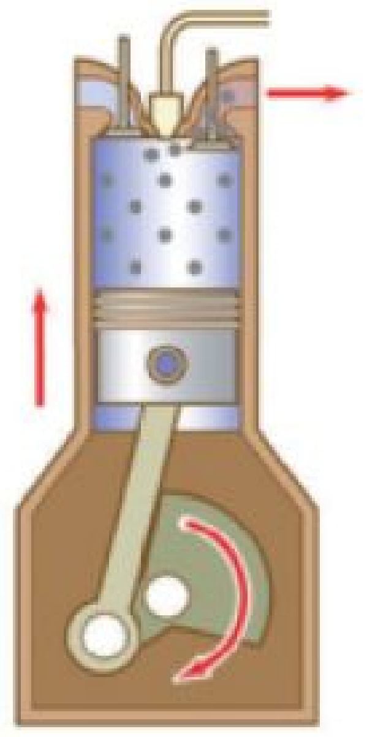
2. Compression

With both valves at the top of the cylinder closed, the crankshaft moves the piston upward, compressing the mixture inside the cylinder (the combustion chamber), increasing its temperature very quickly. When the piston reaches its highest point, the mixture is fully compressed.



3. Power

With the mixture under great pressure and temperature, all that's needed to ignite it is a spark. This is provided by the spark plug, and the resulting controlled explosion is powerful enough to force the piston down to the bottom of the cylinder again, pushing the crankshaft around.



4. Exhaust

As the crankshaft rotates and pushes the piston back up inside the cylinder, the exhaust valve opens at the top to allow the burnt exhaust gases to escape. With the piston back at the top of the cylinder, the exhaust valve closes and the four-stroke cycle starts over.

© SPL; Alamy; Wärtsilä

How do some tyres run even after a puncture?

Not surprisingly, this usually depends on the size of the puncture; the smaller the hole, the more time it will take for air to escape and the tyre to get flat. A bicycle tyre with a slow leak can often be ridden without any problems, although more frequent pumping of the tyre will be needed. In this case the hole can be so small, it is then almost impossible to locate, and a new inner tube is usually the best course of action. Cars today are often fitted with run-flat tyres – reinforced tyres that in the event of a puncture can be ridden at reduced speeds for a limited distance.

What was the fastest round-world trip?

According to the Guinness World Records, the fastest aerial circumnavigation (without going into space) still belongs to Concorde. In 1995, the supersonic passenger jet set off from New York, USA and circled the globe in just 31 hours, 27 minutes and 49 seconds, reaching Mach 2 - twice the speed of sound. The historical flight was made as part of an event to celebrate the anniversary of Christopher Columbus' discovery of America. Steve Fossett set the solo record in 2005 in Virgin Atlantic's GlobalFlyer. He flew 37,000 kilometres (22,991 miles) in 67 hours, two minutes and 38 seconds, without stopping to refuel.

© Anthony Collins

Why use solar-powered boats?

Shipping accounts for 2.7 per cent of all global carbon dioxide emissions (aviation in comparison is less than two per cent). If the amount of carbon in the atmosphere is going to be reduced, maritime travel is one of the key sections to address. Sailing is a tried and tested format, but what about solar power?

A strong candidate for the solar-powered boat crown is the MS Turanor PlanetSolar from the project of the same name. The largest solar-powered boat on Earth, it contains over 500 square metres (5,382 square feet) of solar panels that drive the vessel's two electric motors. The catamaran doesn't generate any carbon emissions and for travel at night or prolonged heavy cloud cover, lithium-ion batteries are used. The boat crossed the Atlantic in 22 days (a record for a solar-powered vessel) and can navigate for up to 72 hours in the dark on battery power. The Turanor is also completely silent so noise pollution is another eliminated problem.

Solar energy has also been proven to work on smaller, less expensive craft. Recently, Englishman Simon Milward created his own small vessel, which successfully crossed the Channel. It's still early days but if the use of solar power can catch on in the maritime world, traversing the seven seas in an environment-friendly way could be a massive step in reducing the human carbon footprint.

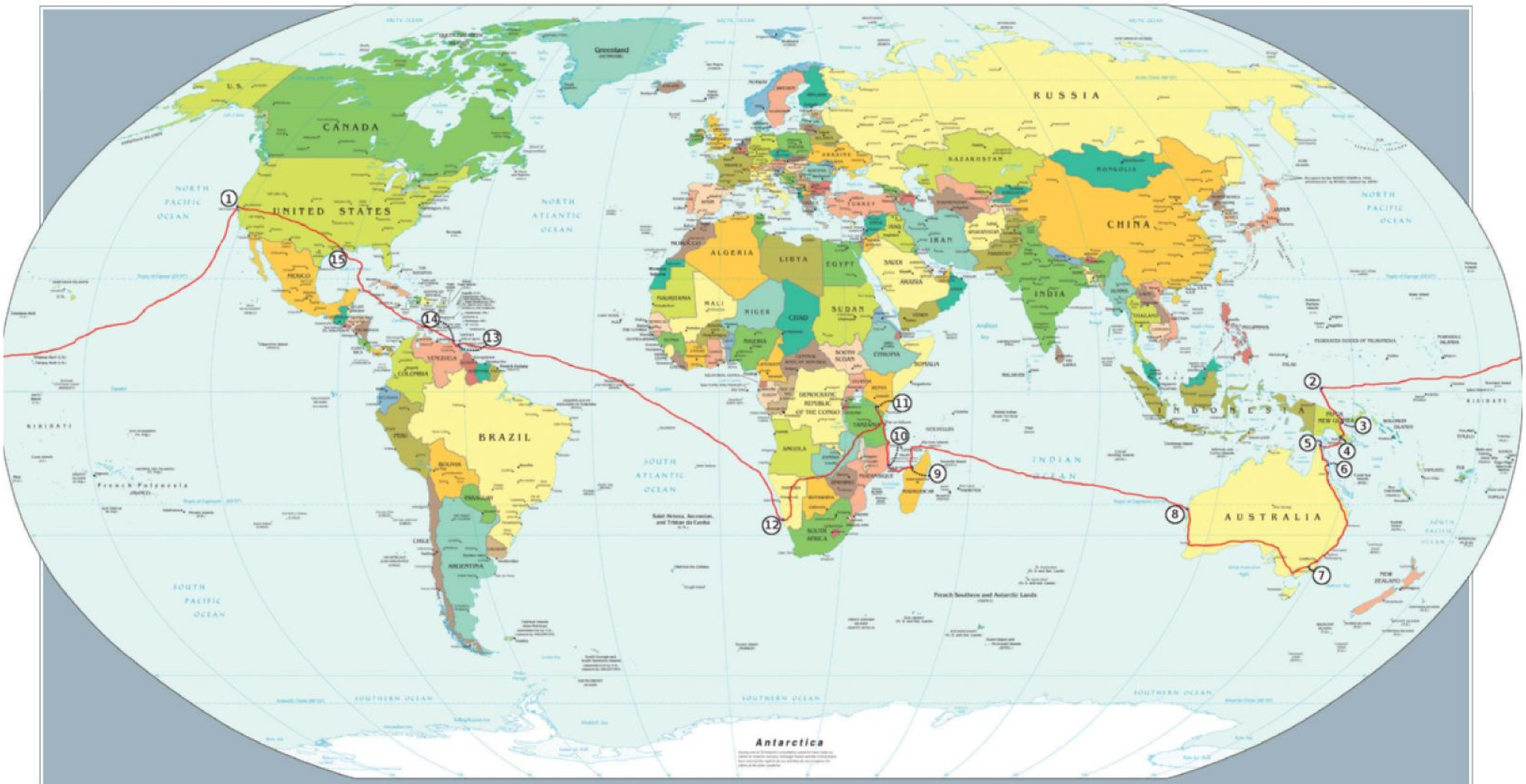
How does brake fluid work?

As cars get ever faster – the Hennessey Venom GT can reach an eye-melting 300 kilometres (186 miles) per hour in 13.63 seconds – the brakes used to stop them must stay up to speed. Braking in cars would not work without the fluid. Brake fluid works because it does not significantly compress. As you press the brake pedal, the force is transferred to pressure in the fluid. This pressure causes the brake pads to squeeze the wheels, converting the kinetic energy to heat via friction and slowing the car down. As a result, it is essential that the fluid has a high boiling point so it doesn't evaporate after prolonged use. If it does begin to evaporate, the effectiveness is seriously compromised because gas can be compressed much easier than a liquid. The boiling point of the fluid is measured in DOT numbers, which stands for the US Department of Transportation. DOT 3, 4, and 5.1 are made of glycol and DOT 5 is silicone based. It is recommended your brake fluid is changed every two years.

What is inertial coupling?

In Inertial coupling is a dangerous effect which can undermine the performance of aircraft trying to manoeuvre at high speed. It is not an aerodynamic effect, but one caused by the simple laws of conservation of angular momentum – when an aircraft attempts to roll at high speed, centrifugal forces cause it to buck, pitch and yaw about all three axes. The effect was discovered when engineers and pilots tried to break the sound barrier in the Forties, and is made worse by long, thin aircraft designs with stubby wings and small tail planes. Enlarging these aerodynamic surfaces helped to negate inertial coupling's dangerous effects.

> "Enlarging these aerodynamic surfaces helped to negate inertial coupling's dangerous effects"



What is the fastest anyone has ever travelled around the world without a vehicle?

On 21 July 2012, Erden Eruc of Around-n-Over became the first person to travel around the world solo under his own power, setting the record at five years and 11 days. He used a bicycle, rowboat and kayak to cover a total distance of 66,299 kilometres (41,196 miles), crisscrossing over the equator and passing every line of longitude.

Eruc broke many records during his trip, becoming the first person to row across three different oceans and spending an incredible 312 days rowing solo across the Pacific. By the time he returned in 2012, he was the most experienced ocean rower in the world.

He took breaks on the way, so his total travel time was 1,026 days, approximately two years and ten months, but a British man thinks that he can beat that time. In September of 2014, Sam Greatrex of Lap the World began his journey to break Eruc's record, aiming to travel 51,500 kilometres by bicycle and rowboat in just 18 months. That's 18,000 miles by bicyle and 14,000 nautical miles by rowboat!

Are there any advantages to cars like the Reliant Robin that have three wheels?

In the 1970s, three-wheeled cars mostly owed their popularity to low prices, but now their efficiency is earning them a newfound respect among hybrid vehicle engineers. Light and aerodynamic, it takes little energy to get a three-wheeled car on the move. Their engines are smaller and less fuel-hungry than those in their four-wheel counterparts, making them economical both to purchase and to run. Three-wheelers' small size also makes them extremely manoeuvrable. Modern versions usually have two wheels at the front and one at the back, making them just as stable as conventional cars.

Why are ships called 'she'?

Some say it's because the men revered their ship like a goddess. Columbus named his ship after the Virgin Mary. Seafarers relied upon their ship to nurture them and keep them nourished, like their wives and mothers. It was bad luck to have women on board, so ship owners used their loved ones' names to keep them in mind. There is another less romantic possibility, though. In some European languages, nouns are considered to be masculine or feminine. Perhaps the word ship was one of the feminine words.

> "Seafarers relied upon their ship to nurture them and keep them nourished"

Science

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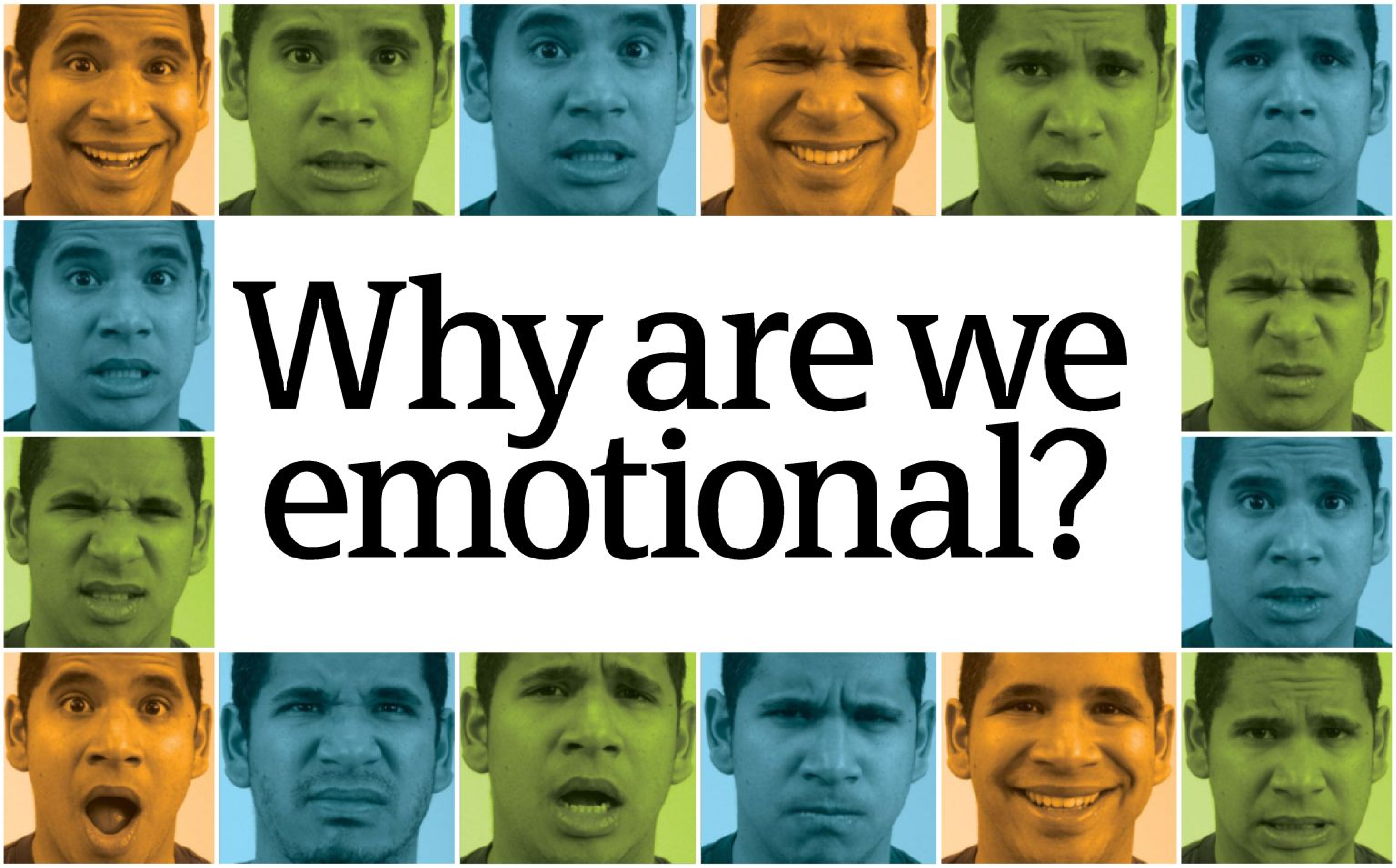
Why are we emotional?



Human emotions are governed by a complex mix of chemicals and electricity – learn all about our moody biology now…

The human brain weighs just over a kilogram (2.2 pounds) and plays host to an estimated 86 billion neurons, and at least as many supporting glial cells. Signals are transmitted along each nerve electrically, by gradients of charged ions. Each neuron makes hundreds of connections to those around it.

At each of the 300 trillion synapses in the human brain, chemicals known as neurotransmitters relay messages from one nerve to another. Each neurotransmitter has a set of corresponding receptors, which can be activatory or inhibitory, helping nerves to fire, or suppressing their activity. This enormous chemical and electrical system provides the complex network that enables us to feel emotion, from the all-consuming addiction of love, to the raw devastation of grief.

Techniques like functional magnetic resonance imaging have helped reveal areas of the brain involved in processing emotional responses. This data, in combination with case studies of patients with damage to areas of their brains, and information gathered from investigations in animals, has enabled us to map of emotional connections in the body.

A notable area of the brain when it comes to mood is the limbic system – a small cluster of interconnected regions involved in memory storage and decision-making. The limbic system is directly connected to the olfactory bulb, which processes incoming smell signals from the nose, providing the biological link that allows odours to recall a memory. Recent research at the Kavli Institute for Systems Neuroscience in Norway suggests smell-based memories are triggered with the activation of corresponding brain waves to those experienced on initially experiencing the scent.

The nucleus accumbens links the limbic system to other areas of the brain also involved in the processing of emotion. For instance, the basal ganglia, at the base of the forebrain, has been well studied for its role in the planning and co-ordination of movement, but certain areas also light up in response to positive emotional stimuli and are thought to be involved in reward and reinforcement. Damage to part of the basal ganglia, known as the ventral pallidum, causes anhedonia – the inability to experience pleasure. The orbitofrontal cortex, located above the eyes, also activates in response to positive experiences, and is thought to play a role in evaluating reward versus punishment.

Compound emotions

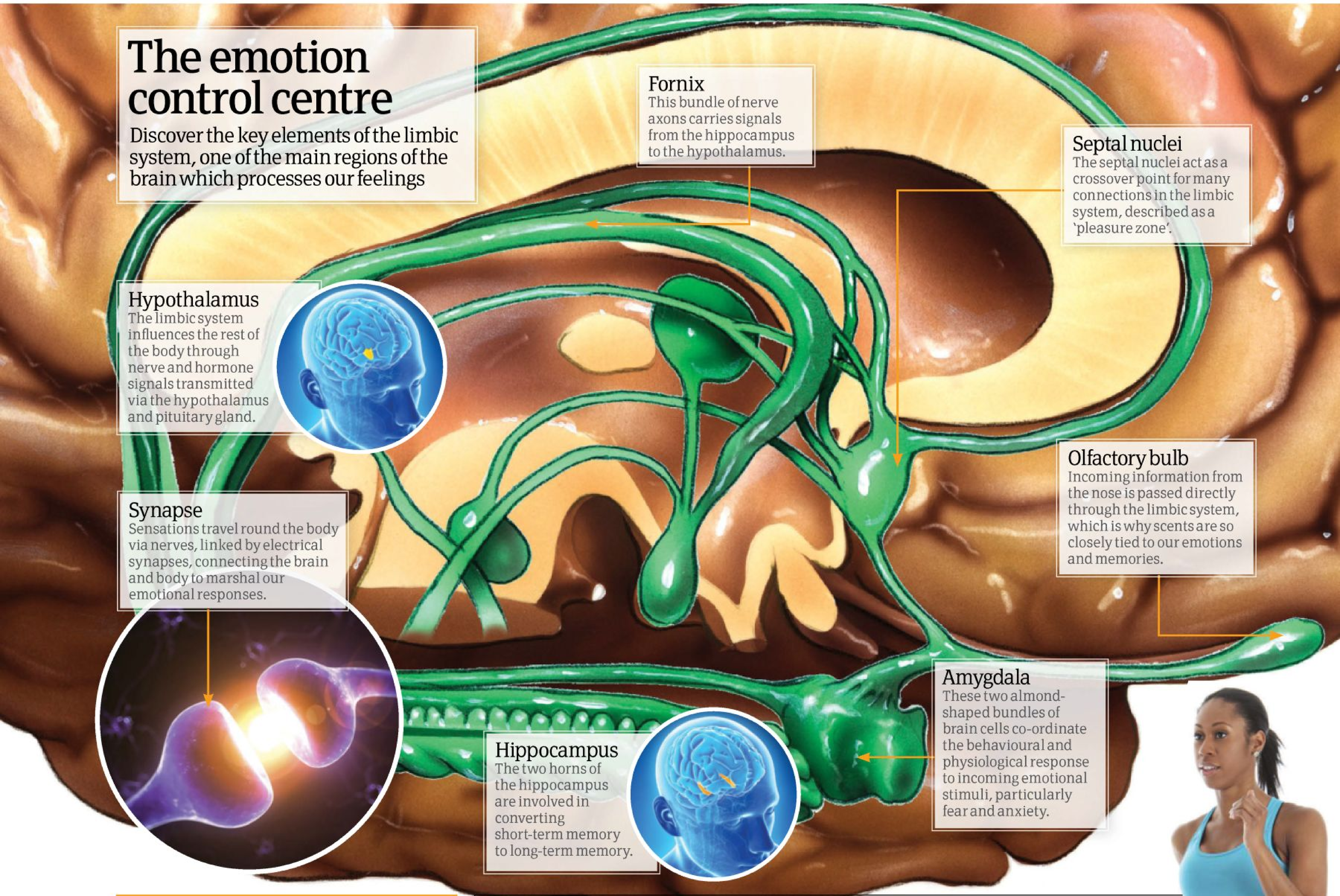
New research by Ohio State University has found that we may have as many as 21 distinct and complex emotional expressions – a few demonstrated in the images above. Hybrid emotions include being 'angrily surprised' or 'happily disgusted' and appear when conflicting feelings are experienced simultaneously. For instance, you may be sad something has ended but happy that you have experienced it. Previous studies suggested that we only had six emotions.

Another approach to the study of complex emotions like happiness is to break them down into smaller parts. Pleasure is evolutionarily ancient and is based on a chemical reward system that acts as a biological incentive to repeat beneficial behaviour. There are several 'reward pathways' in the brain, but the most studied is the mesolimbic pathway.

The pathway transmits dopamine signals from nerves in the middle of the brain, upward and forward, to the limbic system and the prefrontal cortex, which are involved in

The emotion control centre

Discover the key elements of the limbic system, one of the main regions of the brain which processes our feelings



Fornix
This bundle of nerve axons carries signals from the hippocampus to the hypothalamus.

Septal nuclei
The septal nuclei act as a crossover point for many connections in the limbic system, described as a 'pleasure zone'.

Hypothalamus
The limbic system influences the rest of the body through nerve and hormone signals transmitted via the hypothalamus and pituitary gland.

Synapse
Sensations travel round the body via nerves, linked by electrical synapses, connecting the brain and body to marshal our emotional responses.

Olfactory bulb
Incoming information from the nose is passed directly through the limbic system, which is why scents are so closely tied to our emotions and memories.

Amygdala
These two almond-shaped bundles of brain cells co-ordinate the behavioural and physiological response to incoming emotional stimuli, particularly fear and anxiety.

Hippocampus
The two horns of the hippocampus are involved in converting short-term memory to long-term memory.

How do drugs alter our mood?

Humans have been modifying their brain chemistry for medical, religious and recreational purposes for centuries, despite the many risks. Stimulants like caffeine, nicotine, cocaine and amphetamine affect the release of the fight-or-flight chemicals adrenaline and noradrenaline, increasing alertness. While euphoriants like MDMA cause a surge of serotonin, which in turn leads to the release of bonding hormone oxytocin, resulting in a sense of euphoria.

Depressants, including sedatives, hypnotics and alcohol, work on the GABA receptor system to dampen brain activity. GABA is an inhibitory neurotransmitter, and blocks nerve activity, resulting in relaxation and reduced anxiety. Some depressants have anti-convulsant effects, so are used as a treatment for epilepsy.

Opioids also modulate nerve signals. They have a similar structure to natural endorphins bind to their receptors in the brain and spinal cord, resulting in pain relief and euphoria.

Emotional messengers

Dopamine

This neurotransmitter feeds the reward pathway in the brain and is involved in motivation, drive, pleasure and addiction. Abnormally high levels of dopamine are linked to loss of contact with reality, delusions and lack of emotion, while low levels are linked to addictive behaviour and risk taking.

Noradrenaline

Related to adrenaline, this neurotransmitter is a stress hormone that co-ordinates the fight-or-flight response. It mediates many of the physical components of emotion, including raised heart rate, and also acts in the brain to enhance alertness, cognition and decision-making behaviour.

GABA

Gamma-aminobutyric acid (GABA) is the brain's main inhibitory neurotransmitter. It subdues nerve transmission, allowing neurons time to recover. Increased GABA activity reduces anxiety.

Serotonin

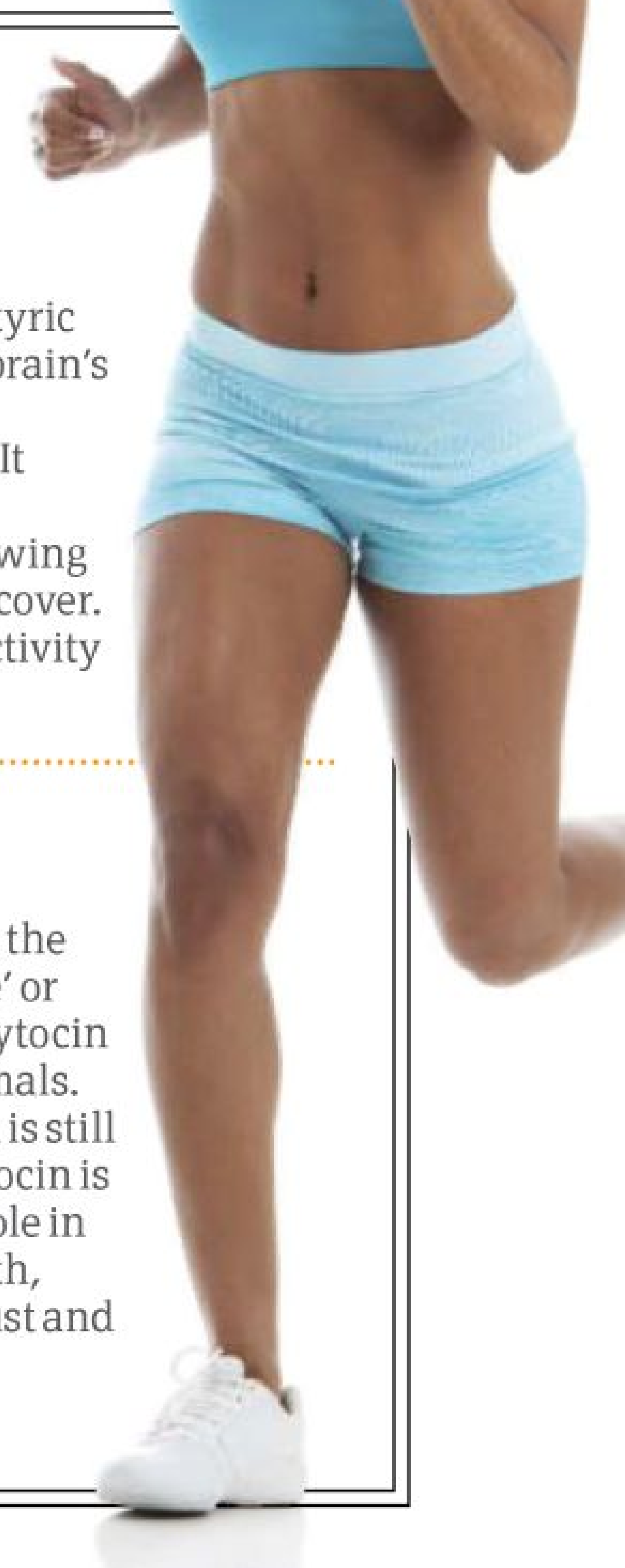
Serotonin was first recognised by scientists for its ability to constrict blood vessels, and has since become widely regarded by scientists as the 'happiness hormone'. Chemically known as 5-hydroxytryptamine (5-HT), increasing the serotonin levels in the brain is the main goal of medical antidepressants.

Beta-endorphin

Endorphins are natural opioids, produced in response to pain, excitement and exercise (pictured). Beta-endorphin binds to the same mu receptors as pain-relieving morphine. Present on nerves in the brain and spinal cord, they modulate neural activity, causing mild sedation, relieving pain and inducing joy.

Oxytocin

Often described as the 'bonding hormone' or 'love hormone', oxytocin is unique to mammals. Although research is still in its infancy, oxytocin is thought to play a role in intimacy, childbirth, sexual arousal, trust and pair bonding.



emotional processing. Under normal conditions, this pathway serves as a motivator for positive actions, producing pleasurable feelings that reinforce beneficial behaviour like eating high-calorie food, social interaction and reproduction. Activation of the pathway also aids in memory retention, increasing the likelihood that the action will be repeated in the future.

Unfortunately, the pleasurable feedback is so strong that abuse of the pathway is common. Many illicit substances, including cocaine, amphetamine and MDMA, affect the mesolimbic pathway, resulting in a pleasurable reward, but also contributing to habituation and addiction.

It's not all about the brain though. The feelings associated with emotions are the result of a complex mixture of incoming sensory messages that come from all over the body.

The autonomic nervous system (more commonly known as ANS) is the subconscious arm of the peripheral nervous system, and is responsible for bodily functions that are not under our voluntary control, such as heart rate, digestion and sweating; it too is wired in to the limbic system.

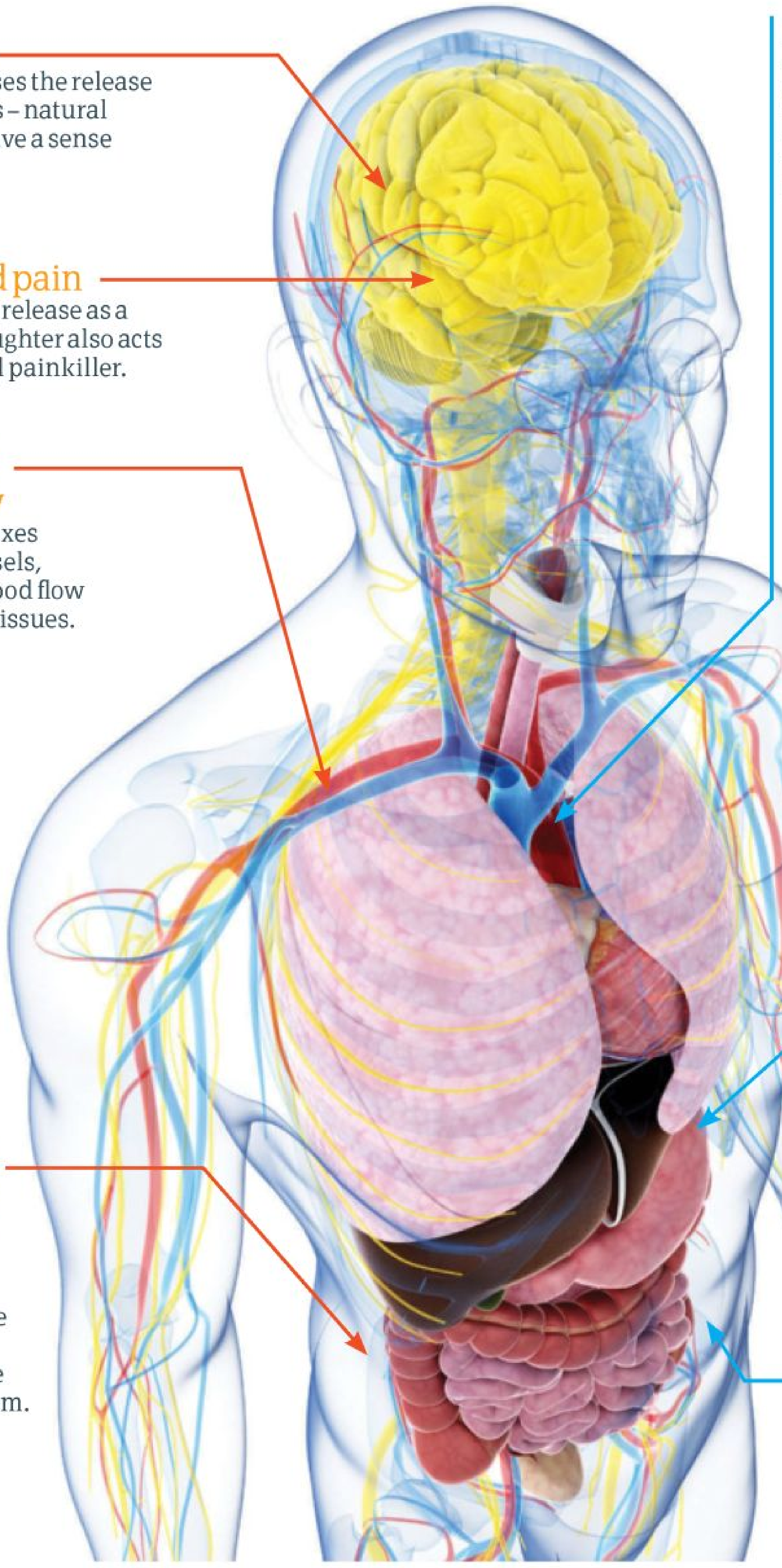
The ANS has two distinct components with opposing functions. The sympathetic nervous

Can we fake a smile?

Faking emotions is harder than it seems. Humans are social animals and have evolved extremely good facial recognition skills – so if something isn't quite right, we are quick to notice. The muscles around our mouths are under fine voluntary nerve control, which not only provides the range of motion required for speech, but also enables us to fake a smile. But people are not easily deceived. Facial expressions involve a multitude of subtle, involuntary muscle movements, and re-creating them is incredibly difficult. The forehead and eyebrows are particularly challenging, as the muscles are mostly under subconscious control. It is hard to achieve the same expression with voluntary muscle contraction, and our eyes are often the biggest giveaway when a smile isn't genuine.

Laughter vs stress

These two opposing states have very different effects on the body, as we reveal here…



Euphoria
Laughter causes the release of endorphins – natural opiates that give a sense of wellbeing.

Reduced pain
Endorphin release as a result of laughter also acts as a natural painkiller.

Increased blood flow
Laughing relaxes the blood vessels, increasing blood flow to the body's tissues.

Improved immunity
There is some evidence that laughter can have a positive effect on the function of the immune system.

Raised blood pressure
Stress causes the heart to beat faster and the blood vessels to constrict, raising blood pressure.

Muscle tension
In response to stress, the body prepares the muscles for activity; very strong emotions like anxiety and anger can lead to shaking.

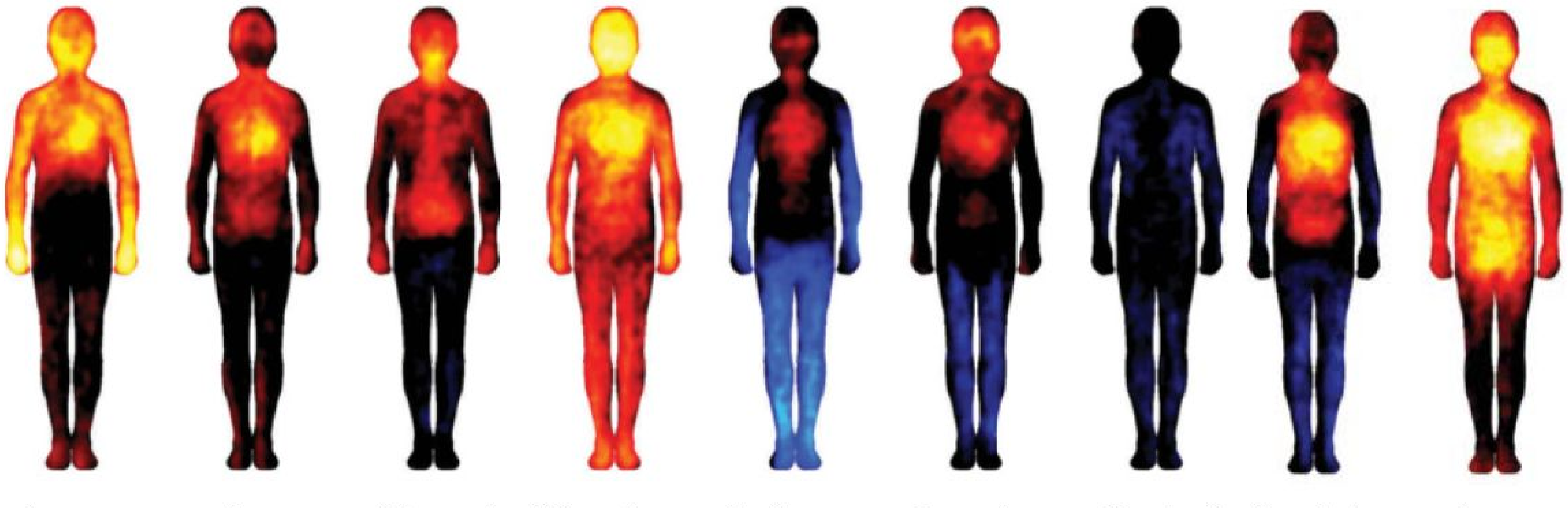
Stomach cramps
In emotionally challenging situations, the brain diverts blood away from the digestive system, prioritising muscles and brain.

Sweaty palms
As part of the fight-or-flight response, the sympathetic nervous system activates sweat glands on the hands, feet and in the armpits.

Lowered immunity
The stress hormone cortisol (which is produced in the adrenal glands; not shown) suppresses the activity of the immune system.

Mapping out emotions

The complex human emotions are the result of sensory signals from the rest of the body. Researchers at Finland's Aalto University charted the areas of the body most commonly associated with different feelings to produce maps of where we experience the major emotions. The images demonstrate how different emotions trigger different levels of sensation around the body. Here high levels of sensation are represented with warmer hues, and vice versa.



Emotions are often influenced by physical stimuli, be it food, behaviour or environmental factors like sunlight

system uses the neurotransmitters adrenaline and noradrenaline to prepare the body for 'fight or flight', raising the heart rate and mobilising resources to fuel the muscles. The parasympathetic nervous system uses acetylcholine to allow the body to rest and digest, slowing the heart and breathing, and diverting the blood supply to the gut.

Sensory feedback produced by the effects of the autonomic nervous system contribute to many of the familiar feelings associated with emotions. Stimulation of the heart by adrenaline and noradrenaline as part of the fight-or-flight response produces the rapid palpitations associated with anger, fear and embarrassment. Its actions on the digestive system cause 'butterflies in the stomach', and activity at the glands on the hands, feet and in the armpits, leads to sweating when nervous.

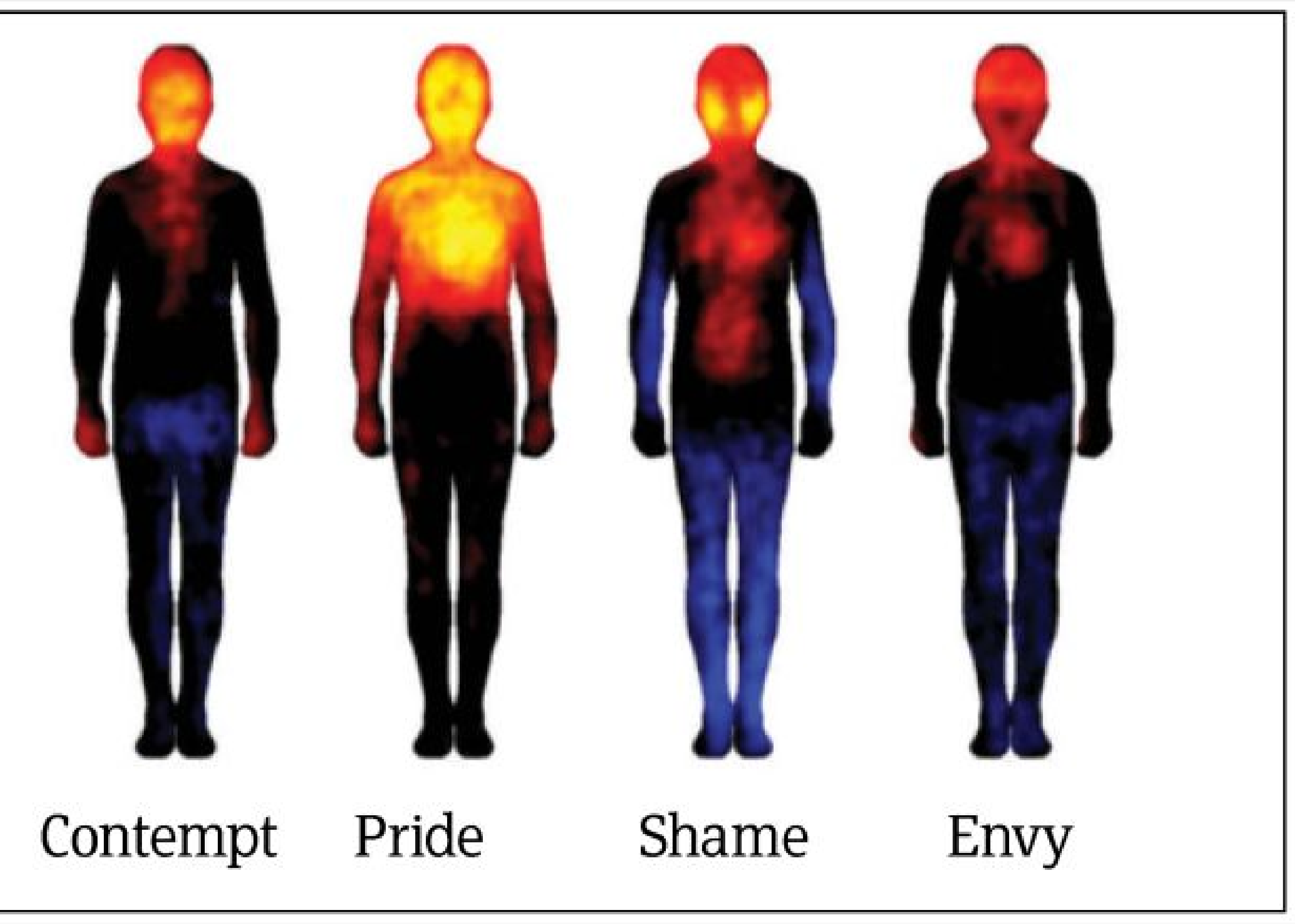
More passive emotions, like sadness or contentment, on the other hand, require little physical response, and the parasympathetic nervous system takes control of the heart, slowing its rate. Feelings of contentment and relief are often accompanied by deep, slow breathing – another indicator of parasympathetic activity.

The limbic system is also connected to the body via the hypothalamus. This small region, located on the underside of the brain, links the nervous system to the endocrine system, which produces hormones – some of which are key mediators of mood and emotion. For example, corticotropin-releasing hormone is produced in response to stress, and leads to the release of the stress hormone cortisol from the adrenal glands above the kidneys.

The regulation of emotion is not just restricted to one area of the brain – it involves almost the entire body. Reducing the bewildering complexity of human emotion down to anatomy, physiology and, ultimately, brain chemistry, might seem clinical and overly simplistic, but in reality, the fact that humans are capable of experiencing such an extraordinary range of abstract feelings is one of the greatest wonders of biology, with many chemical puzzles still waiting to be solved in this area.

Fight or flight

The autonomic nervous system is responsible for the control of heart rate, blood pressure and respiration, and governs the function of most of the internal organs. It's divided into two parts. The sympathetic nervous system is responsible for the fight-or-flight response and is behind raised heart rate, sweating, nausea and shaking associated with action-based emotions like anger and anxiety. While the parasympathetic nervous system has the opposite effect and plays a bigger role in more passive emotions like sorrow and contentment.



5 happiest countries

(based on wealth, economic growth and quality of life, 2013)

1. Norway
2. Switzerland
3. Canada
4. Sweden
5. New Zealand

3 unhappiest occupations in the UK (2014)

1. Publican
2. Elementary construction
3. Debt collection

HAPPIEST and SADDEST states in the United States

(Gallup-Healthways Well-Being Index, 2013)

HAPPIEST	SADDEST
1. North Dakota	1. West Virginia
2. South Dakota	2. Kentucky
3. Nebraska	3. Mississippi

25%

Of 129 gold medal ceremonies at the London 2012 Olympics, 25 per cent of FEMALE ATHLETES CRIED, compared to just eight per cent of male competitors

SMILIEST country Brazil

Travel app Jetpac analysed INSTAGRAM IMAGES BY COUNTRY, ranking photos based on whether the subject had a wide grin or a tight-lipped smile. Brazil finished first, while the USA lagged behind in 33rd place. The UK ranked 62nd and Japan came bottom

23 69

LIFE SATISFACTION peaks at the AGES of 23 and 69, according to the London School of Economics (2013)

© Alamy; Thinkstock; Lauri Nummenmaa/Aalto University; Ohio State University

How are heart transplants performed?

Discover what happens in one of the most complex surgeries

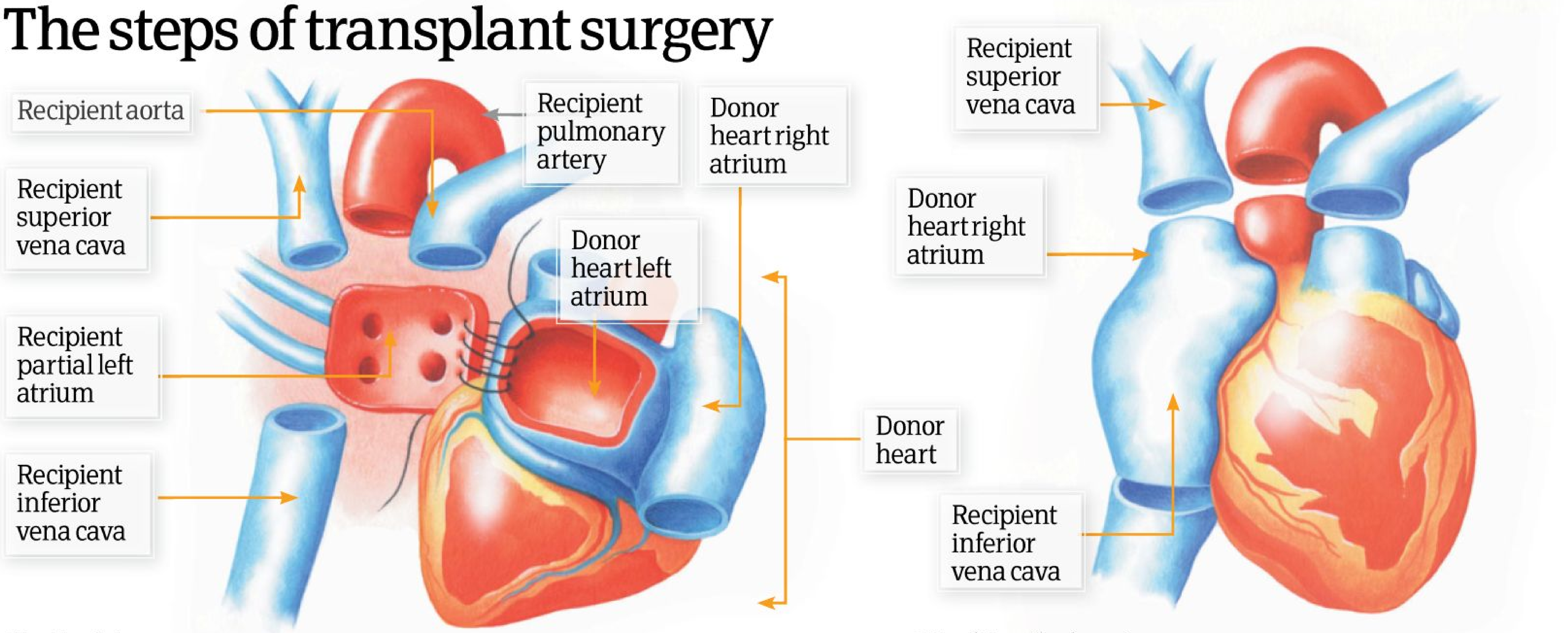
Heart transplants are a life-saving treatment that can restore a patient's quality of life.

Selecting suitable people for a heart transplant is a carefully controlled process. There are strict criteria to ensure maximum possibility of success, preventing wastage of any precious donor hearts. A heart transplant is recommended if a patient has severe heart failure, where not enough blood is being pumped around the body. Causes of this include diseases of heart muscles (cardiomyopathy) and a variety of genetic cardiac diseases. Patients typically have to pass psychological and emotional testing, be willing to take lifelong medications and have a current expected survival time of less than one year without transplant. Sometimes, newborn babies are affected, with ultrasound tests revealing structural problems meaning that the heart cannot pump enough blood. Further blood tests to rule out current infections and confirm tissue compatibility are performed.

The technical process of transplantation is complex and demanding for both patients and cardiac surgeons. The first step involves retrieval of the heart from the donor, at which time other organs might be harvested. The receiving patient is given a general anaesthetic and a cut made through the breastbone (sternum) to access the heart. A heart-lung bypass machine is then started, and the heart transplant takes place. At the end of the operation, the new heart is tested, and if it's pumping blood successfully, the bypass machine is removed, the breastbone closed and the patient is moved to an intensive care unit.

After the operation, lifelong medications are taken to prevent the body rejecting the new heart. These include immunosuppressants, which reduce the patient's natural immunity, so their body does not reject their new heart.

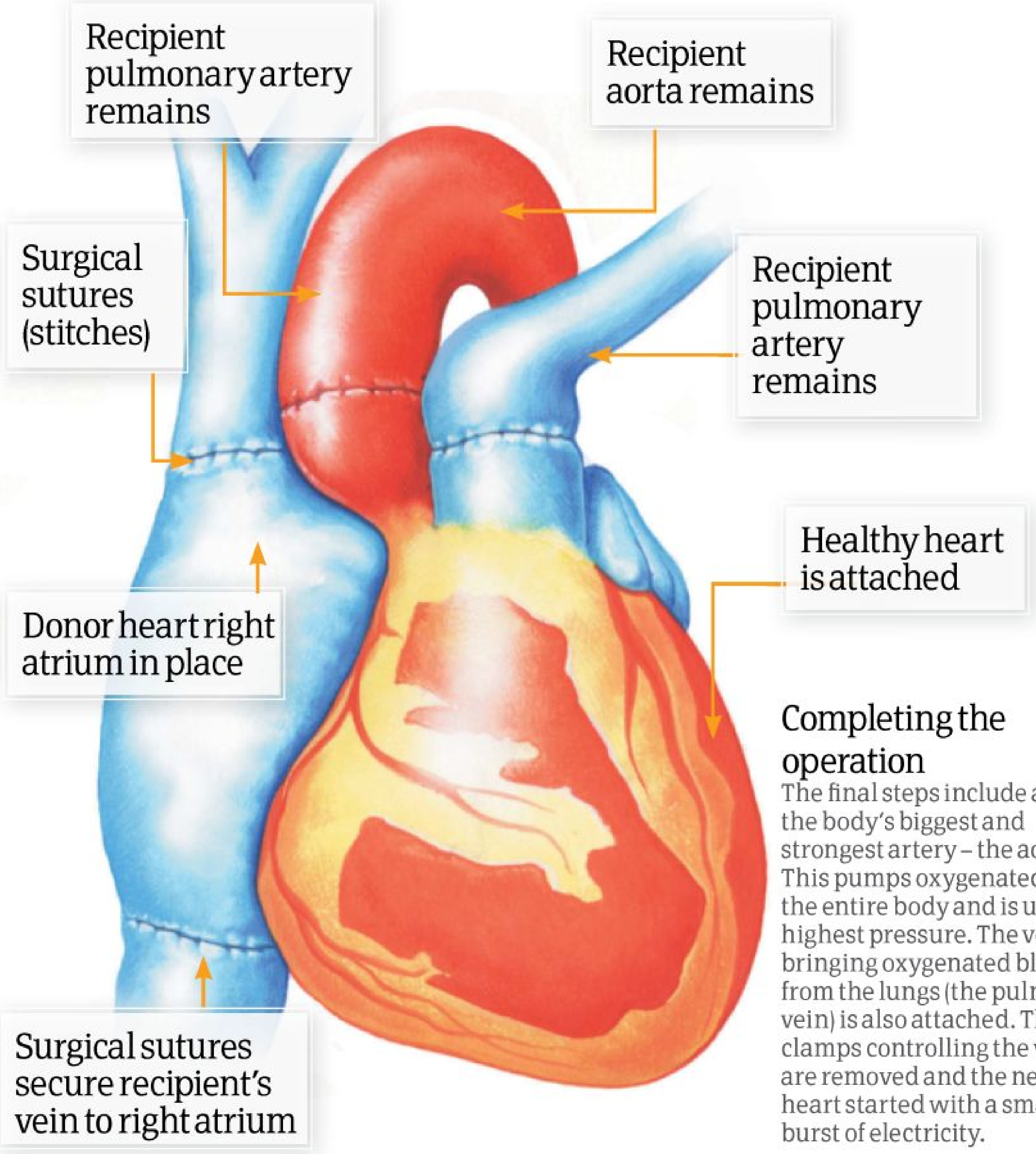
The steps of transplant surgery


Recipient aorta
Recipient superior vena cava
Recipient partial left atrium
Recipient inferior vena cava
Recipient pulmonary artery
Donor heart right atrium
Donor heart left atrium
Donor heart
Recipient superior vena cava
Donor heart right atrium
Recipient inferior vena cava

First incision
The sternum is cut with a special saw that doesn't damage the softer tissues underneath. The sac containing the heart (pericardium) is cut open and the patient placed on a heart-lung bypass machine. The blood vessels and chambers of the old heart are disconnected, leaving the back wall of the left atrium in place, which acts as the starting point for attaching the new heart.

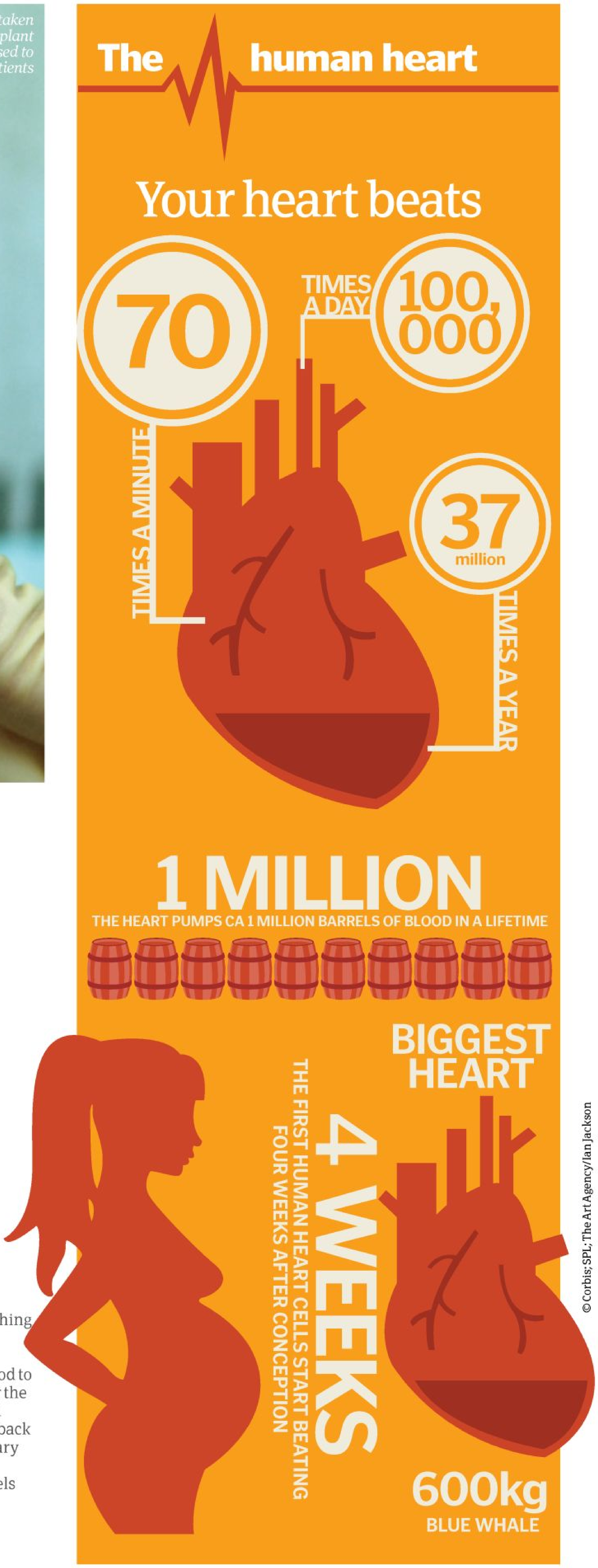
Attaching the heart
The veins carry blood back toward the heart. The biggest – the inferior and superior vena cava – drain into the right atrium. These are carefully attached to the new heart, which fixes the donor right atrium into place. Tiny stitches are sewn using very sharp needles, special needle holders and a steady hand!

Parts of a heart taken from a donor or transplant recipient can be used to treat other patients


Recipient pulmonary artery remains
Recipient aorta remains
Surgical sutures (stitches)
Recipient pulmonary artery remains
Healthy heart is attached
Donor heart right atrium in place
Surgical sutures secure recipient's vein to right atrium

Completing the operation

The final steps include attaching the body's biggest and strongest artery – the aorta. This pumps oxygenated blood to the entire body and is under the highest pressure. The vessel bringing oxygenated blood back from the lungs (the pulmonary vein) is also attached. The clamps controlling the vessels are removed and the new heart started with a small burst of electricity.



© Corbis; SPL; The Art Agency/Ian Jackson

Can we fight the war against superbugs?

Learn how bacteria will hide, change, lie and cheat to evade antibiotics and secure their survival

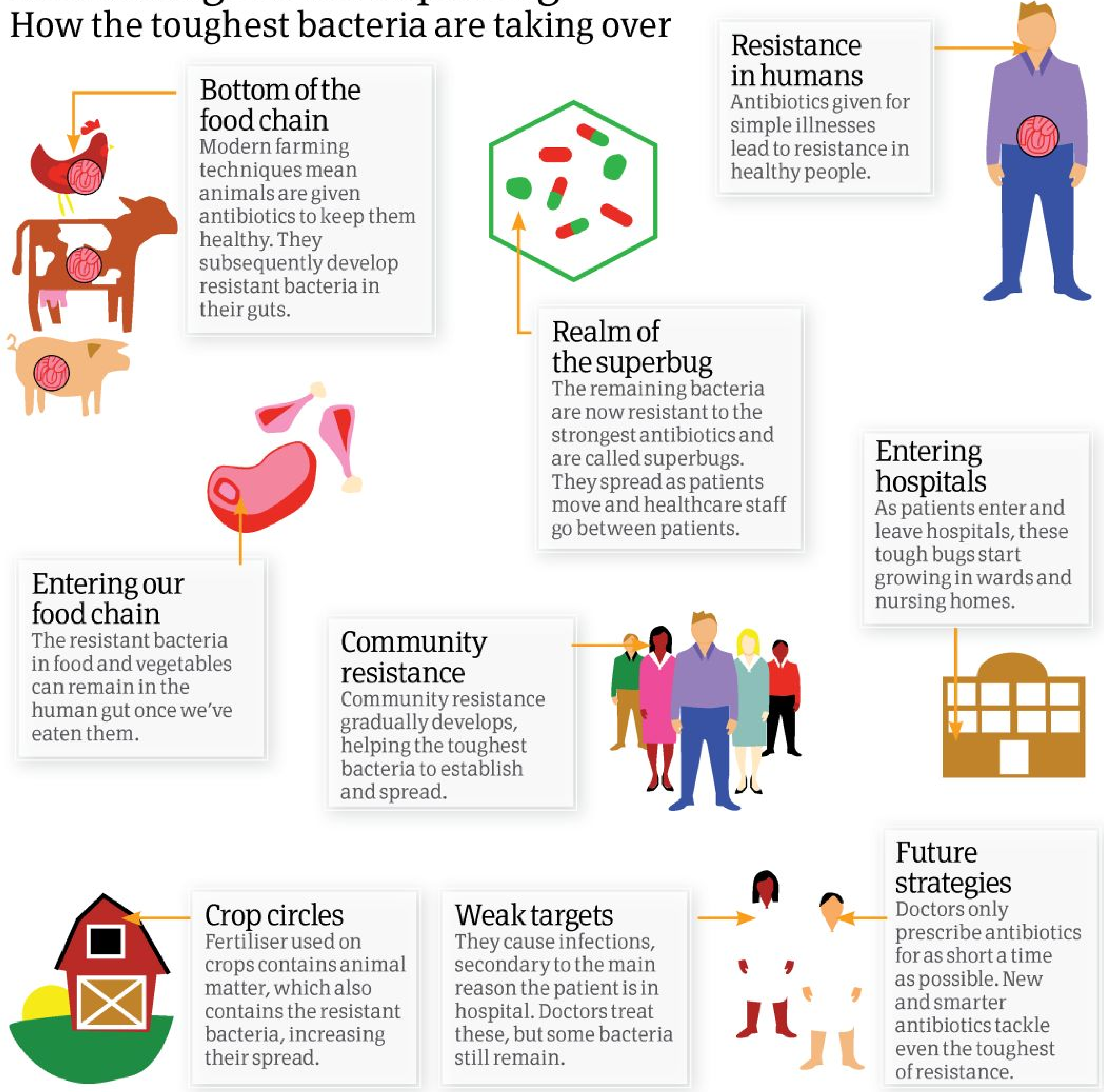
Bacteria are vital to our survival. They help us digest food, keep our skin clean from more harmful organisms and help develop our advanced immunity while we're young. However, they can also cause disease, which ranges from simple eye infections to life-threating illnesses.

Antibiotics were discovered in 1928 and almost overnight they changed what were once fatal diseases into trivial infections. But despite effective medication, bacteria are smart and know how to fight back. They can change their shape, hide in plain sight and alter their surface appearance. After an attack from antibiotics, the few bacteria left over are the strongest of the bunch and are resistant to the current crop of antibiotics; this is true survival of the fittest. The lasting bacteria then multiply, become stronger and are able to survive attacks from other antibiotics. This is known as 'multidrug resistance' and has led to certain bacteria being ominously called 'superbugs.'

Over the last 30 years, it's been stated that too many antibiotics have been prescribed, which has contributed to this resistance. This is why doctors no longer give antibiotics for simple colds; they have no effect on viruses but contribute to antibiotic resistance.

The revenge of the superbug

How the toughest bacteria are taking over



Resistance in humans
Antibiotics given for simple illnesses lead to resistance in healthy people.

Bottom of the food chain
Modern farming techniques mean animals are given antibiotics to keep them healthy. They subsequently develop resistant bacteria in their guts.

Realm of the superbug
The remaining bacteria are now resistant to the strongest antibiotics and are called superbugs. They spread as patients move and healthcare staff go between patients.

Entering hospitals
As patients enter and leave hospitals, these tough bugs start growing in wards and nursing homes.

Entering our food chain
The resistant bacteria in food and vegetables can remain in the human gut once we've eaten them.

Community resistance
Community resistance gradually develops, helping the toughest bacteria to establish and spread.

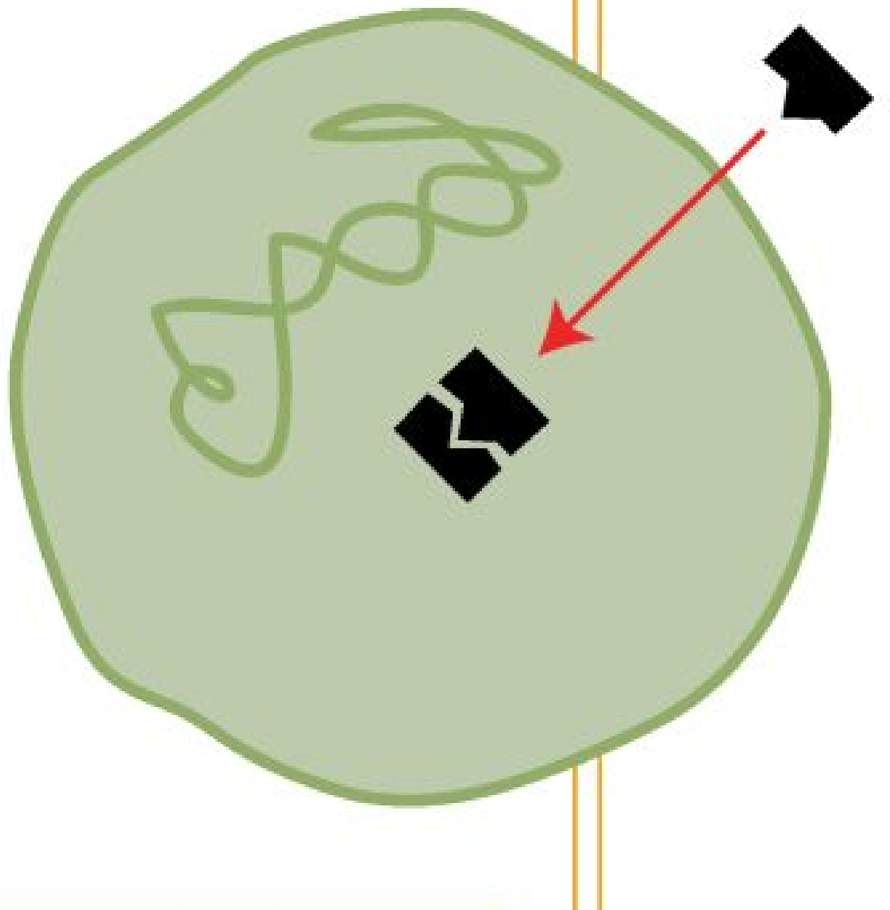
Crop circles
Fertiliser used on crops contains animal matter, which also contains the resistant bacteria, increasing their spread.

Weak targets
They cause infections, secondary to the main reason the patient is in hospital. Doctors treat these, but some bacteria still remain.

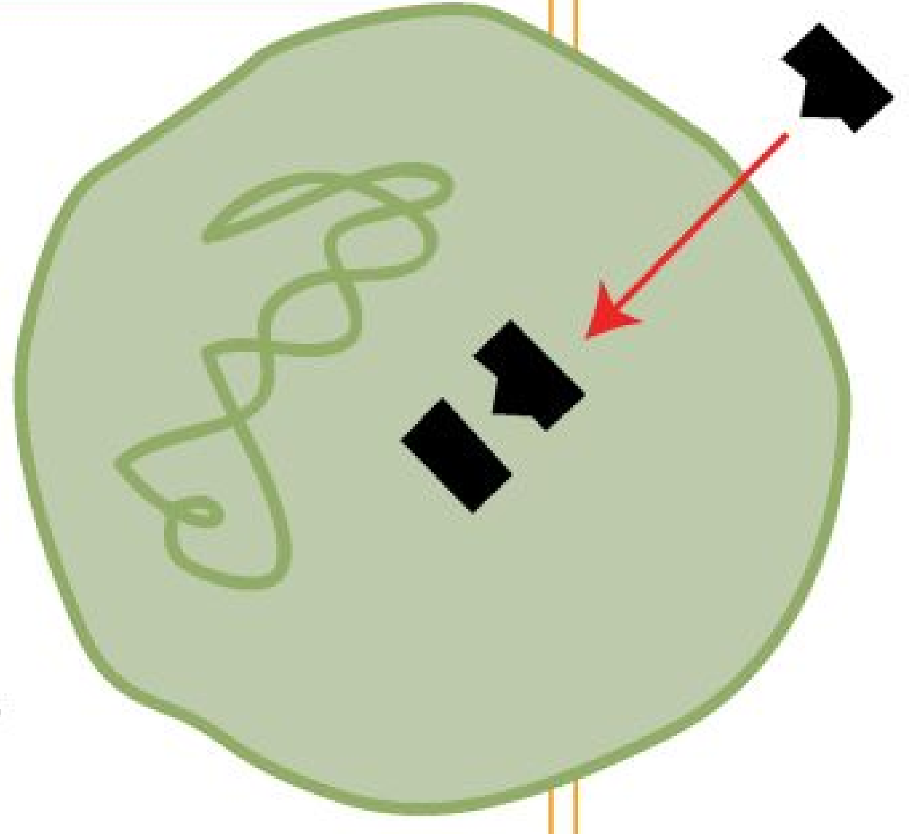
Future strategies
Doctors only prescribe antibiotics for as short a time as possible. New and smarter antibiotics tackle even the toughest of resistance.

How antibiotic resistance develops

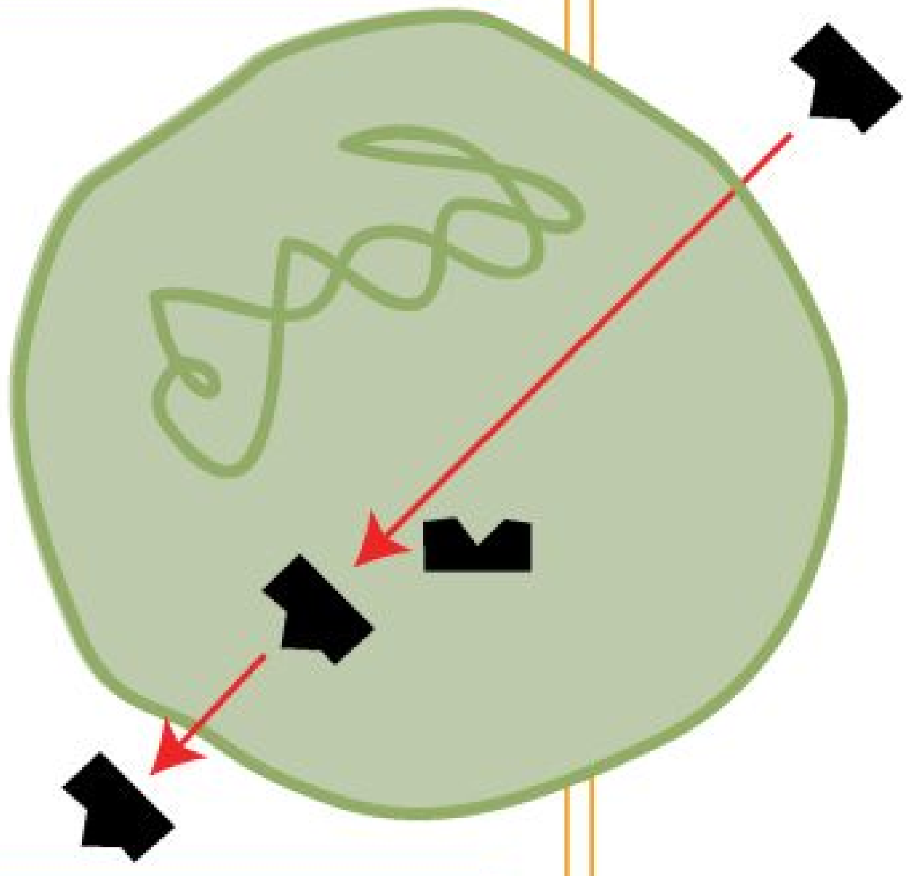
Normal function
Antibiotics target bacterial cells, by changing the signals of their outer wall, their membrane shape, impairing DNA function in the cell or by blocking protein synthesis.



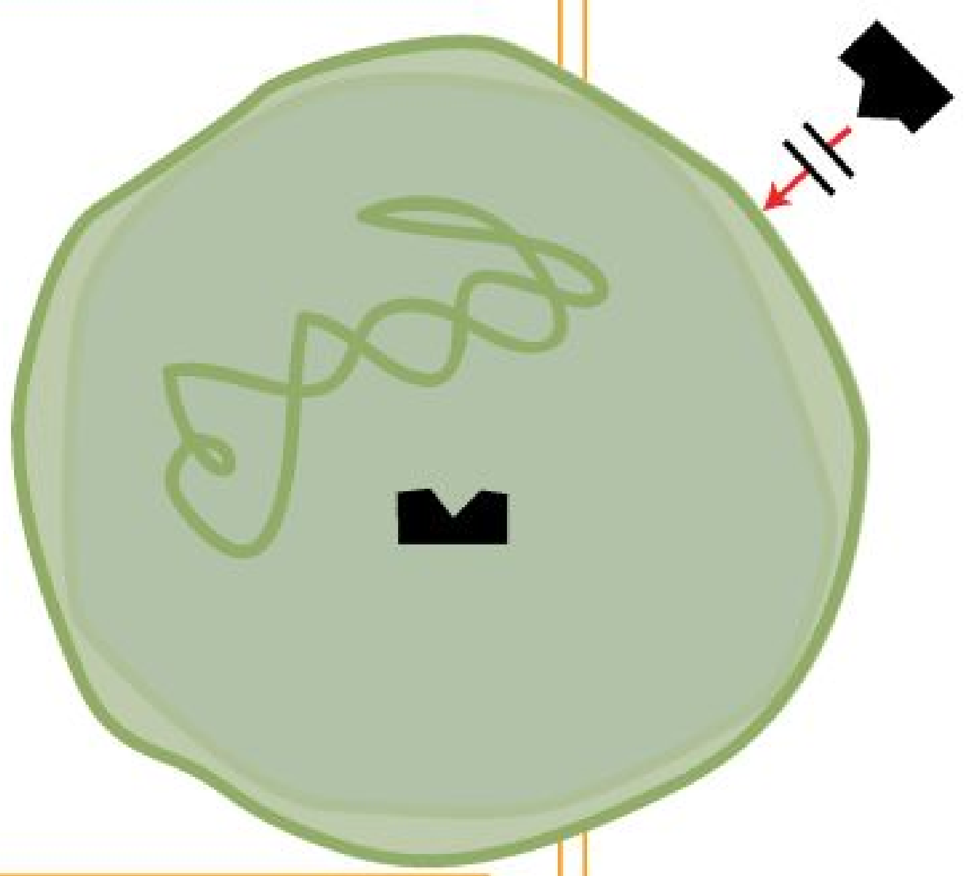
Changing the landing zone
Bacteria can change the shape and structure of the molecules that antibiotics target, meaning they can't recognise them and rendering them useless.



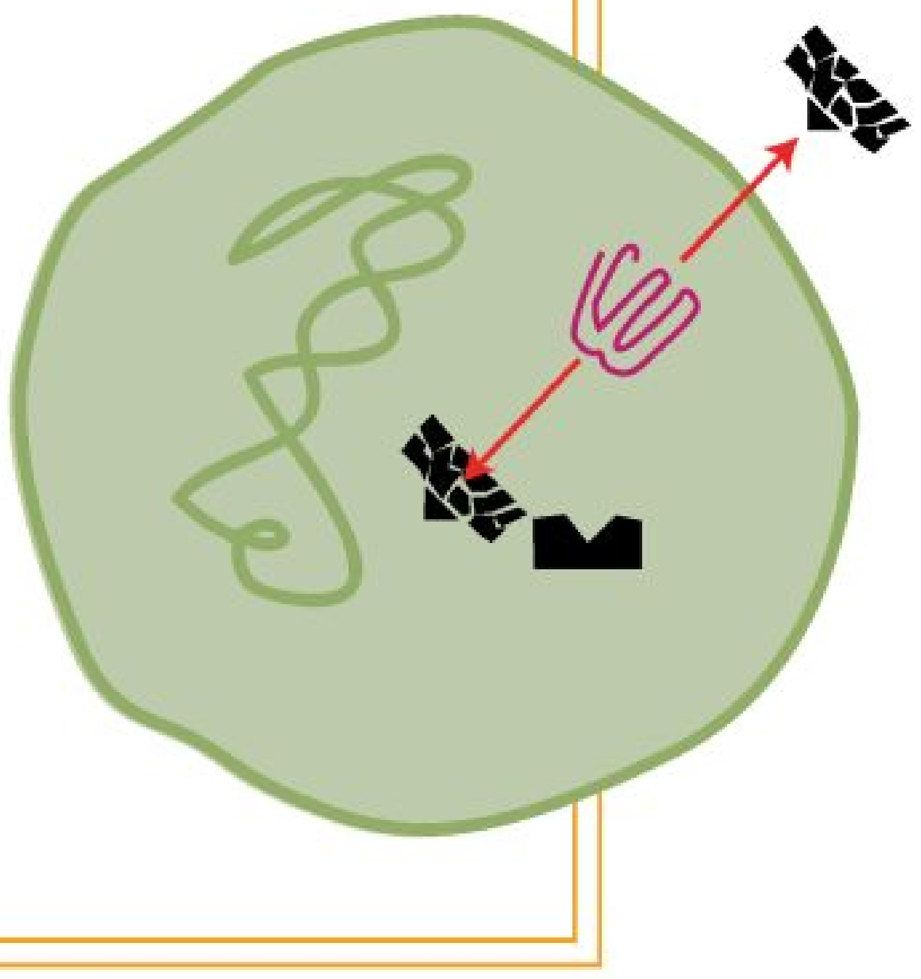
One in, one out
Antibiotics enter bacterial cells via special pumps. The bacteria can develop more exit than entry pumps, meaning the antibiotic is exited faster than it can enter.



Entry policy
Bacteria can stop antibiotics entering: they can change the shape of entry pumps and reduce the size of pores, meaning the antibiotics are too large to enter.



Inactivation
The strongest bacteria are able to develop special enzymes, which can destroy the key parts of an antibiotic before they even have a chance to take effect.



What is wave diffraction?

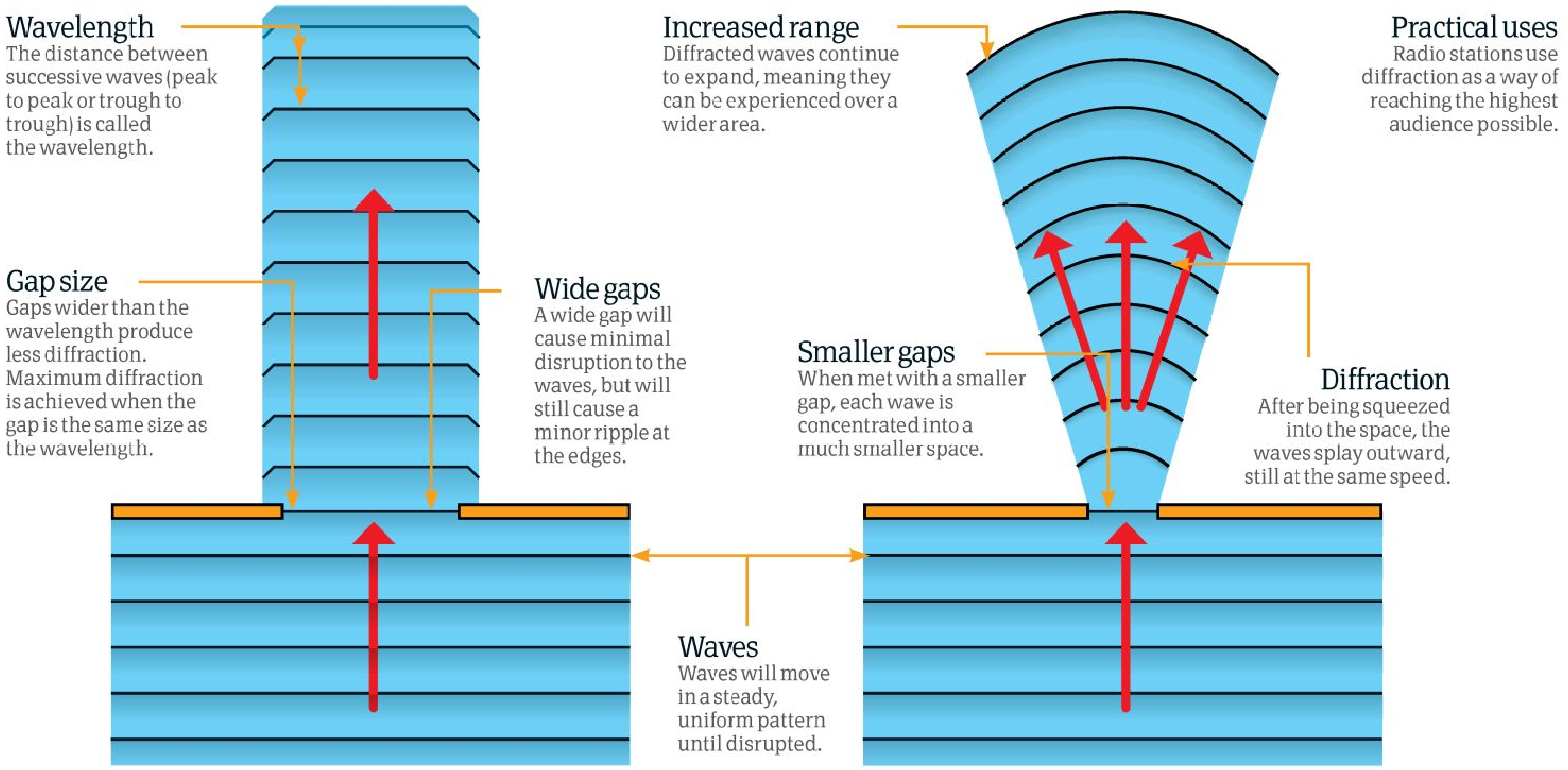
What force makes waves spread outward?

Sound waves move very much like those you see in water, except that they're invisible to the human eye

Waves are very uniform and will happily travel in straight lines forever. Unfortunately for them, there are lots of things that get in their way and when something does, it causes the waves to spread out. This is called diffraction.

When a wave meets an obstacle, it will wrap itself around it, so even though it doesn't change speed it does change direction. Waves that have had to negotiate an obstacle tend to fan out, like expanding ripples on a pond.

Diffraction explains how you can hear things despite not being in a direct line with the source. Someone standing around the corner can make a sound, which travels in a wave. As it reaches the edge of the wall, it's able to spread out, which is how you can hear around corners even though you can't see around them.



Wavelength
The distance between successive waves (peak to peak or trough to trough) is called the wavelength.

Gap size
Gaps wider than the wavelength produce less diffraction. Maximum diffraction is achieved when the gap is the same size as the wavelength.

Wide gaps
A wide gap will cause minimal disruption to the waves, but will still cause a minor ripple at the edges.

Increased range
Diffracted waves continue to expand, meaning they can be experienced over a wider area.

Practical uses
Radio stations use diffraction as a way of reaching the highest audience possible.

Smaller gaps
When met with a smaller gap, each wave is concentrated into a much smaller space.

Diffraction
After being squeezed into the space, the waves splay outward, still at the same speed.

Waves
Waves will move in a steady, uniform pattern until disrupted.

What is pressure?

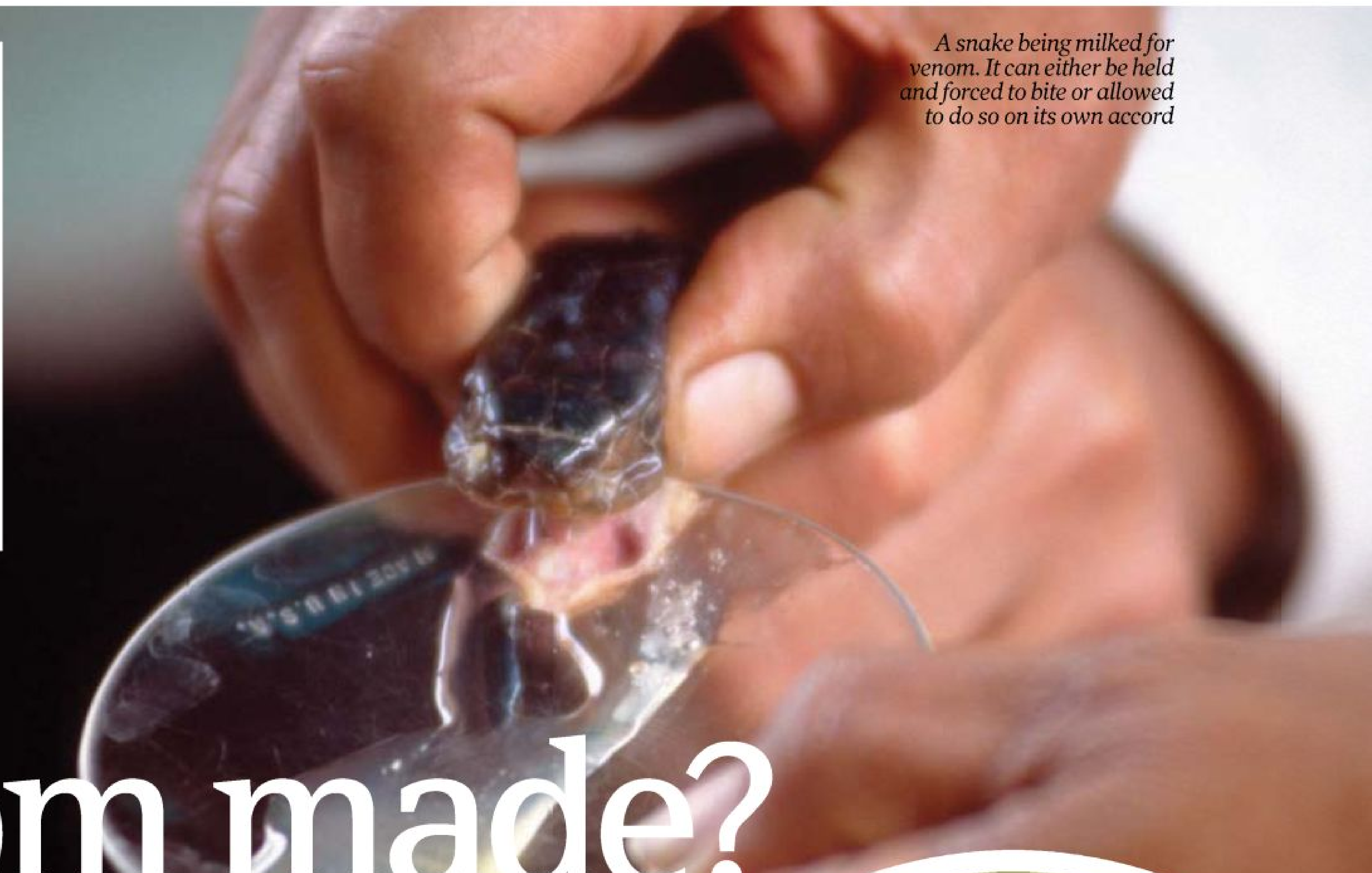
Find out how this powerful force is measured

Pressure is an invisible force that is always acting on us, even if we can't feel it. That is because all matter, regardless of its size, has mass.

Pressure is measured by dividing the amount of force exerted by an object by the area of that object. Force is measured in Newtons and is worked out by calculating the object's mass multiplied by acceleration.

An object with force of ten Newtons and an area of ten square metres (107.6 square feet), therefore creates one Pascal of pressure. Even something as light as air exerts a force, so right now, the atmosphere around us is exerting pressure on us. Having a weight placed on your head or going underwater increases the pressure on your body simply because the force acting on you is increased.

© Thinkstock; Dreamstime



A snake being milked for venom. It can either be held and forced to bite or allowed to do so on its own accord

How is antivenom made?

How is nature's deadliest venom transformed into its own cure?

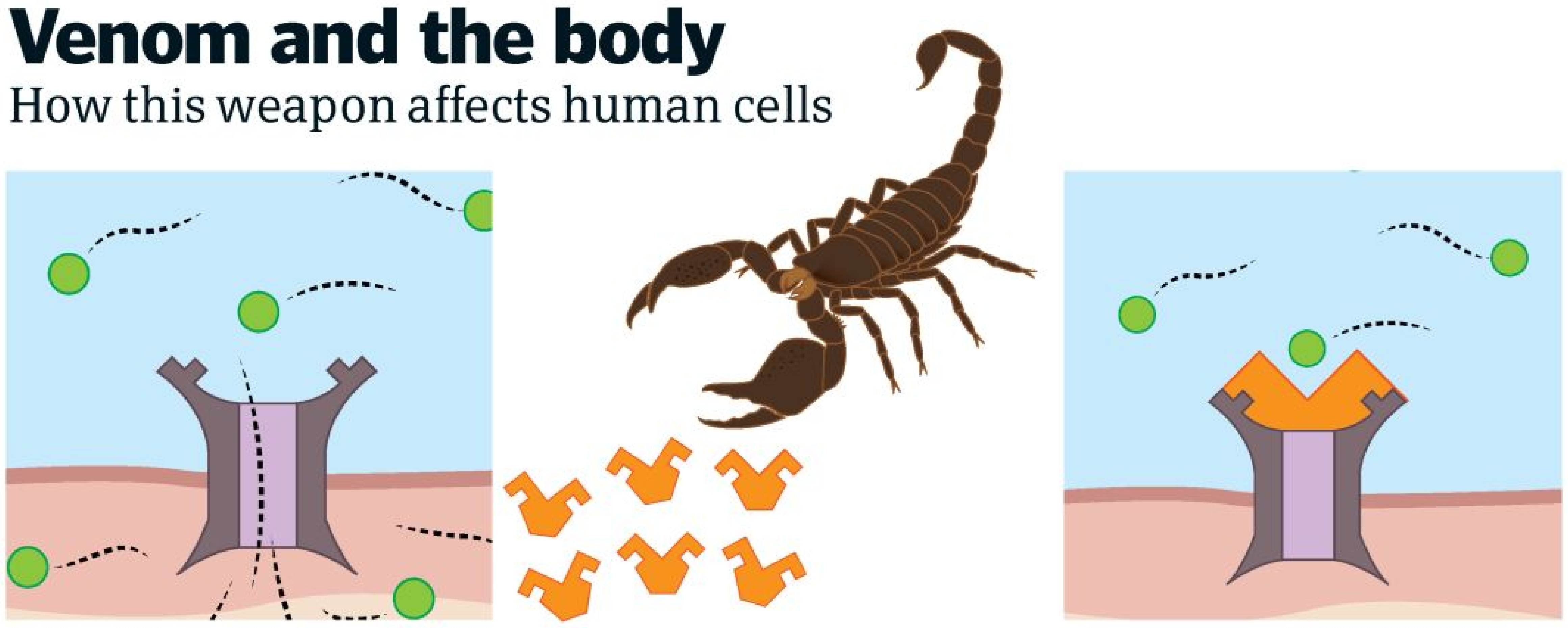
Whether it's a deadly cobra, spider or scorpion, antivenoms offer us one final lifeline against otherwise fatal stings and bites. At current estimates, snake bites alone are responsible for up to 100,000 deaths every year, so the production and development of antivenom is vitally important.

The process was devised in 1894 by French bacteriologist Albert Calmette, a student of Louis Pasteur. The poisonous animal is 'milked' for venom by gently pressing on the venom glands to test on horses, sheep or goats, etc. The chosen animal is injected with a minute amount of the venom (so little they suffer no ill effects) and its body responds by creating antibodies. These antibodies are then collected via a small blood sample taken from the animal and cooled at two to eight degrees Celsius (35.6 to 46.4 degrees Fahrenheit). A centrifuge (inset above) is then used to separate the plasma in the blood before enzymes are introduced to break down the antibody to get antivenom. Types of venom vary considerably between species so this process must be repeated for a wide range of animals.

Antivenom is similar to vaccinations but has one key difference. Vaccinations are used to teach human antibodies to develop a resistance against a disease. However, the nature and ferocity of venom means the body can never create enough antibodies to fight back fast enough. Therefore, ready-made 'donor' antibodies are the perfect solution. With this backup, the body's defences can multiply and attack the venom molecules, neutralising them before they destroy cells.

Venom and the body

How this weapon affects human cells



1. Before venom
A muscle cell receives chloride ions via channels on its surface. These have a specific shape that will only allow matching molecules to pass in or out of the cell to facilitate activity.

2. Venom injected
The venom – in this case, of the deathstalker scorpion – contains chlorotoxin, a protein chain that is also perfectly shaped to fit in the chloride ion channel.

3. Channel blocked
The chlorotoxin blocks chloride ions from entering or exiting the muscle cell. This stops the cell from functioning properly, causing paralysis and, if not treated, death.

© Getty; Alamy; Thinkstock

Getting to know the snake whisperer

William 'Bill' Haast is probably the world's most famous snake handler. Bitten a reported 172 times, Haast was the USA's leading producer of venom for use in serums. Around 36,000 samples were sent to laboratories each year by the 'snake man'. He would milk the snakes with his bare hands and send off vials on virtually a daily basis. Very dangerously, Haast would also inject himself with venom so he could build up his natural defences. As a result, he gained an immunity to many types of snake, so transfusions from his blood helped save others. The pioneering, if unorthodox, advancer of antivenom died in 2011 of natural causes, aged 100.

What's inside a nucleus?

Dissecting the control centre of a cell

Surrounded by cytoplasm, the nucleus contains a cell's DNA and controls all of its functions and processes such as movement and reproduction.

There are two main types of cell: eukaryotic and prokaryotic. Eukaryotic cells contain a nucleus while prokaryotic do not. Some eukaryotic cells have more than one nucleus – called multinucleate cells – occurring when fusion or division creates two or more nuclei within the cytoplasm.

At the heart of a nucleus you'll find the nucleolus; this particular area is essential in the formation of ribosomes. Ribosomes are responsible for making proteins out of amino acids which take care of growth and repair.

Being so important, the nucleus is the most-protected part of the cell. In animal cells it is always located near its centre and away from the membrane to ensure it has the maximum cushioning. As well as the jelly-like cytoplasm around it, the nucleus itself is filled with nucleoplasm, a viscous liquid which maintains its structural integrity.

Conversely, in plant cells, the nucleus is more sporadically placed. This is due to the larger vacuole in a plant cell and the added protection that is granted by a cell wall.

Central command

Take a peek at what's happening inside the 'brain' of a eukaryotic cell

❶ Nuclear pore
These channels control the movement of molecules between the nucleus and cytoplasm.

❷ Nuclear envelope
Acts as a wall to protect the DNA within the nucleus and regulates cytoplasm access.

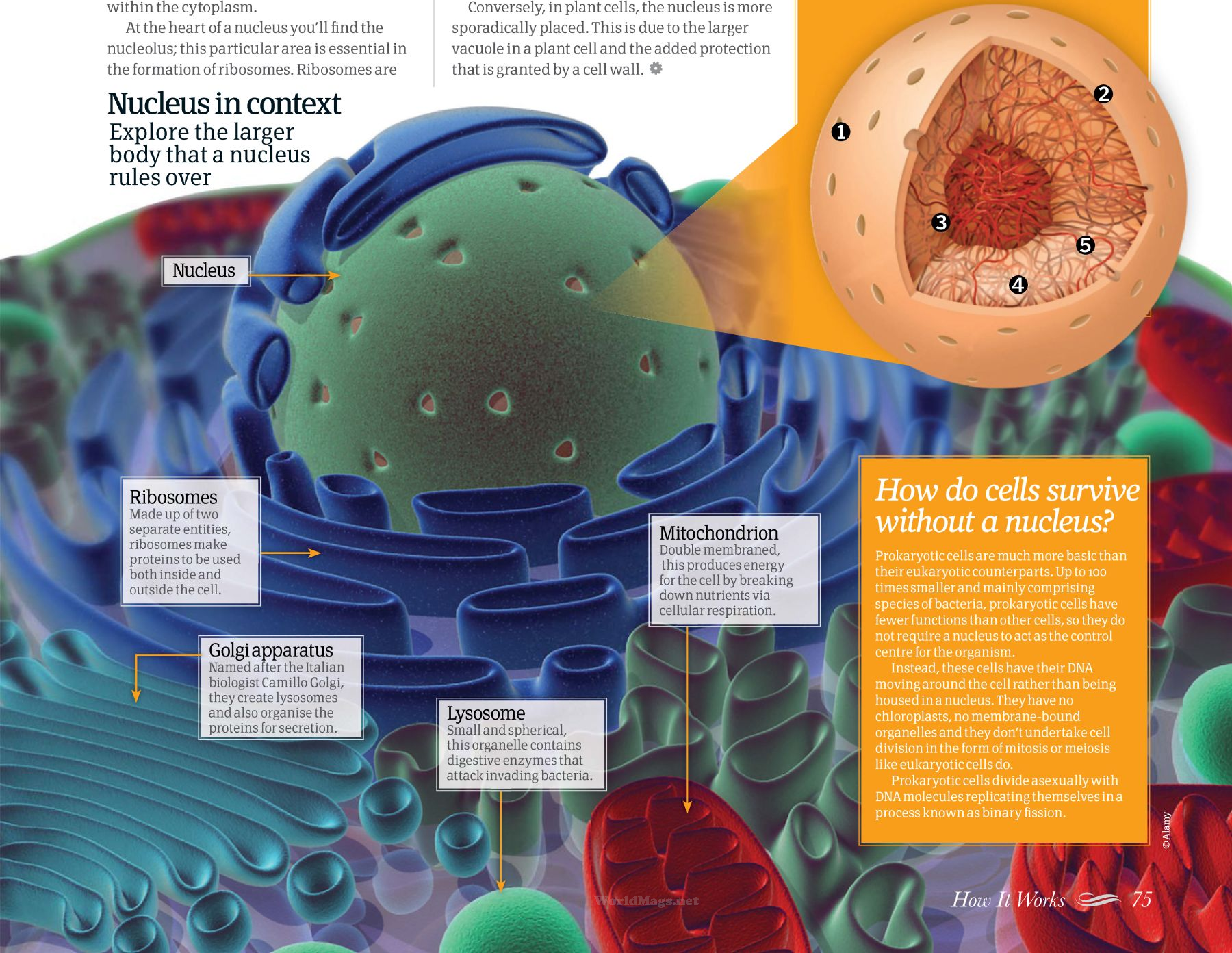
❸ Nucleolus
Made up of protein and RNA, this is the heart of the nucleus which manufactures ribosomes.

❹ Nucleoplasm
This semi-liquid, semi-jelly material surrounds the nucleolus and keeps the organelle's structure.

❺ Chromatin
Produces chromosomes and aids cell division by condensing DNA molecules.

Nucleus in context

Explore the larger body that a nucleus rules over



Ribosomes
Made up of two separate entities, ribosomes make proteins to be used both inside and outside the cell.

Golgi apparatus
Named after the Italian biologist Camillo Golgi, they create lysosomes and also organise the proteins for secretion.

Lysosome
Small and spherical, this organelle contains digestive enzymes that attack invading bacteria.

Mitochondrion
Double membraned, this produces energy for the cell by breaking down nutrients via cellular respiration.

How do cells survive without a nucleus?

Prokaryotic cells are much more basic than their eukaryotic counterparts. Up to 100 times smaller and mainly comprising species of bacteria, prokaryotic cells have fewer functions than other cells, so they do not require a nucleus to act as the control centre for the organism.

Instead, these cells have their DNA moving around the cell rather than being housed in a nucleus. They have no chloroplasts, no membrane-bound organelles and they don't undertake cell division in the form of mitosis or meiosis like eukaryotic cells do.

Prokaryotic cells divide asexually with DNA molecules replicating themselves in a process known as binary fission.

© Alamy

How is laser eye surgery performed?

How surgeons are able to restore your sight with lasers

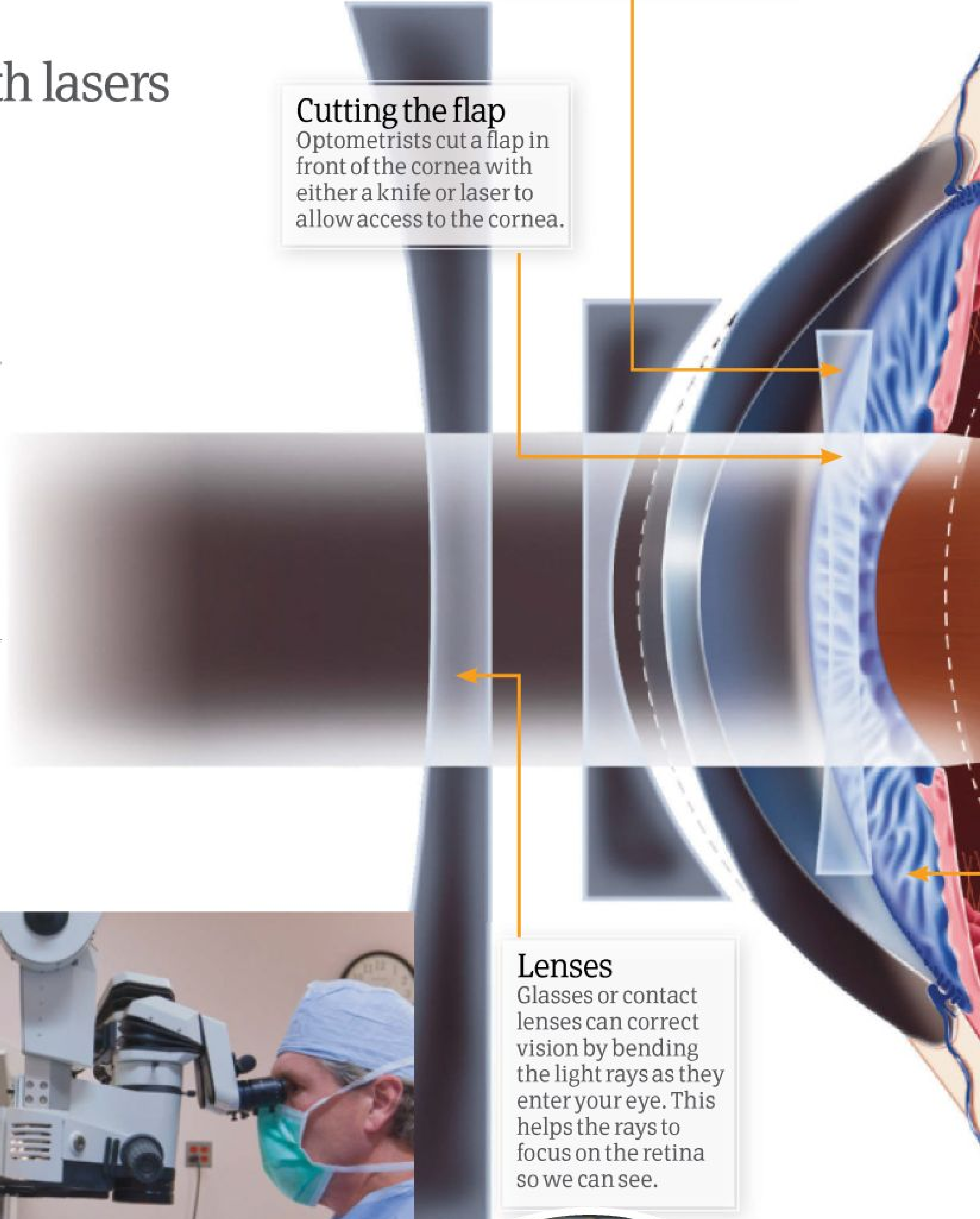
Lasers have been used to help people with short and long-sightedness for a couple of decades, but the practice of using incisions in a person's eye to improve their vision has been around for over 100 years.

It all started in 1898 when eye surgeons would make small cuts in the front surface of the eye (cornea), to flatten it in the middle and let light reach the retina more easily. As this technique was a bit hit-and-miss, they came up with a new technique that involved using a thin blade to slice open the cornea and create a flap. The eye surgeon would then slice a bit of tissue from the cornea to flatten it as before and then fold the flap back down.

The technology took a huge leap forward when they brought lasers into the equation. These incredibly precise laser beams were able to burn away part of the cornea without creating a flap, but this did lead to a very long and uncomfortable recovery.

Then, in 1999, LASIK entered the arena. This procedure, combining two previous methods, required a flap to be made and then the laser could get to work with shaping the stroma layer of the cornea. This allowed for more precision than ever before and vastly reduced the discomfort from the previous method.

The actual surgery takes a surprisingly short amount of time. From the point at which the numbing drops get popped in, the creation of a flap, reshaping and replacing it should take between 15 and 30 minutes, with full vision returning within 24 hours. ✱



Reshaping
As the cornea is curved, they will slice a bit off the front so the light isn't refracted so much and can reach the retina at the correct point.

Cutting the flap
Optometrists cut a flap in front of the cornea with either a knife or laser to allow access to the cornea.

Lenses
Glasses or contact lenses can correct vision by bending the light rays as they enter your eye. This helps the rays to focus on the retina so we can see.

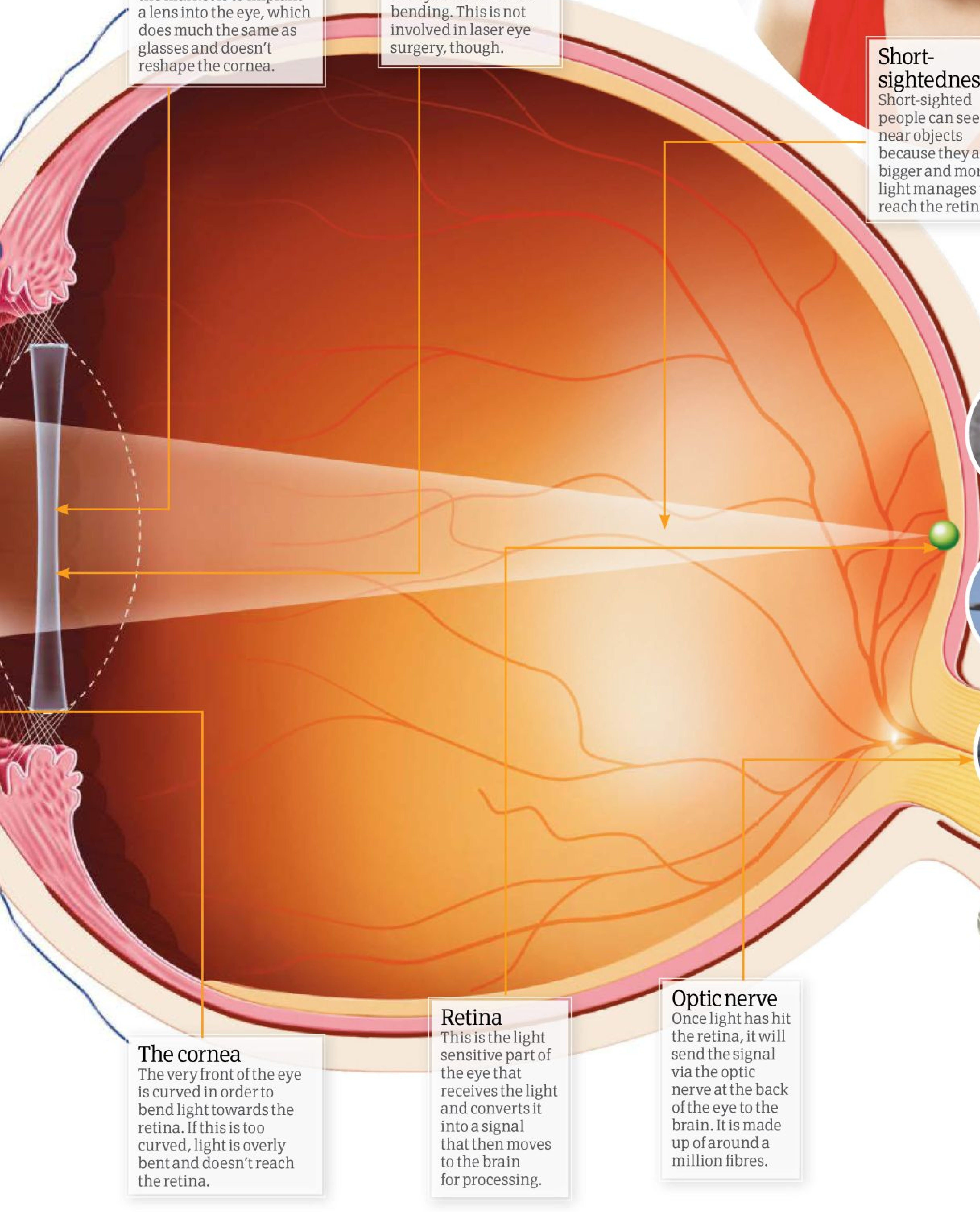
What else can laser eye surgery do?

Laser eye surgery is not limited to curing long and short-sightedness. Modern technology is also able to cure astigmatism, which happens when a person's cornea is an irregular shape, which means light doesn't enter the retina cleanly and is bounced about, resulting in blurred vision. The laser is able to reshape the cornea. The cornea in a short-sighted eye is bent too much, so when light enters, the image gets formed too early and becomes blurry when things are far away. The opposite applies to long-sightedness, as the cornea isn't bent enough.

Laser eye surgery has taken giant leaps forward in the last two decades

A look inside the eye

How does surgery correct a short-sighted eyeball?



Intraocular lens
The newest technique on the market is to implant a lens into the eye, which does much the same as glasses and doesn't reshape the cornea.

Lens
The lens also is responsible for bending light. As it travels through, it will hit the curved lens of the eye and continue bending. This is not involved in laser eye surgery, though.

Short-sightedness
Short-sighted people can see near objects because they are bigger and more light manages to reach the retina.

The cornea
The very front of the eye is curved in order to bend light towards the retina. If this is too curved, light is overly bent and doesn't reach the retina.

Retina
This is the light sensitive part of the eye that receives the light and converts it into a signal that then moves to the brain for processing.

Optic nerve
Once light has hit the retina, it will send the signal via the optic nerve at the back of the eye to the brain. It is made up of around a million fibres.

An eye for numbers

We've all heard about 20/20 vision, but what exactly does that mean? Well, eye specialists have worked out how tall letters have to be for a normal eye to be able to see them at 20 feet (6.1 metres). Someone with 20/20 vision can see letters of that height from 20 feet, meaning their vision is just as expected. Someone with 20/40 vision can see something at 20 feet that a person with normal vision can see at 40 feet (12.2 metres). So, the bigger the second number, the worse the vision.

Scale of sight

20/2

Vision of a falcon, over eight times better than a human

20/20

Normal vision – minimum requirement to be a fighter pilot

20/40

Worst your eyes can be and still be allowed to drive

20/80

Still just about able to read newspaper headlines

20/200

Legally blind – however, you still can see STOP signs

© SPL; Getty; Thinkstock

How can Ebola spread?

Discover how this deadly virus attacks the body and spreads between humans

If you've looked at a newspaper or television in the past couple of months, then it's likely you will have heard of Ebola. The 2014 outbreak in West Africa has caused thousands of deaths across Guinea, Liberia, and Sierra Leone, leaving many people confused and scared about this infectious and often fatal disease.

Ebola virus disease (EVD) is spread via contact with the blood, bodily fluids and organs of an infected person or animal. A person only becomes infectious once their symptoms start to show, which is usually two to 21 days after infection. The initial symptoms are a sudden onset of fever fatigue, muscle pain, headache and sore throat, followed by vomiting, diarrhoea and rashes, eventually leading to impaired kidney and liver function, as well as internal and external bleeding.

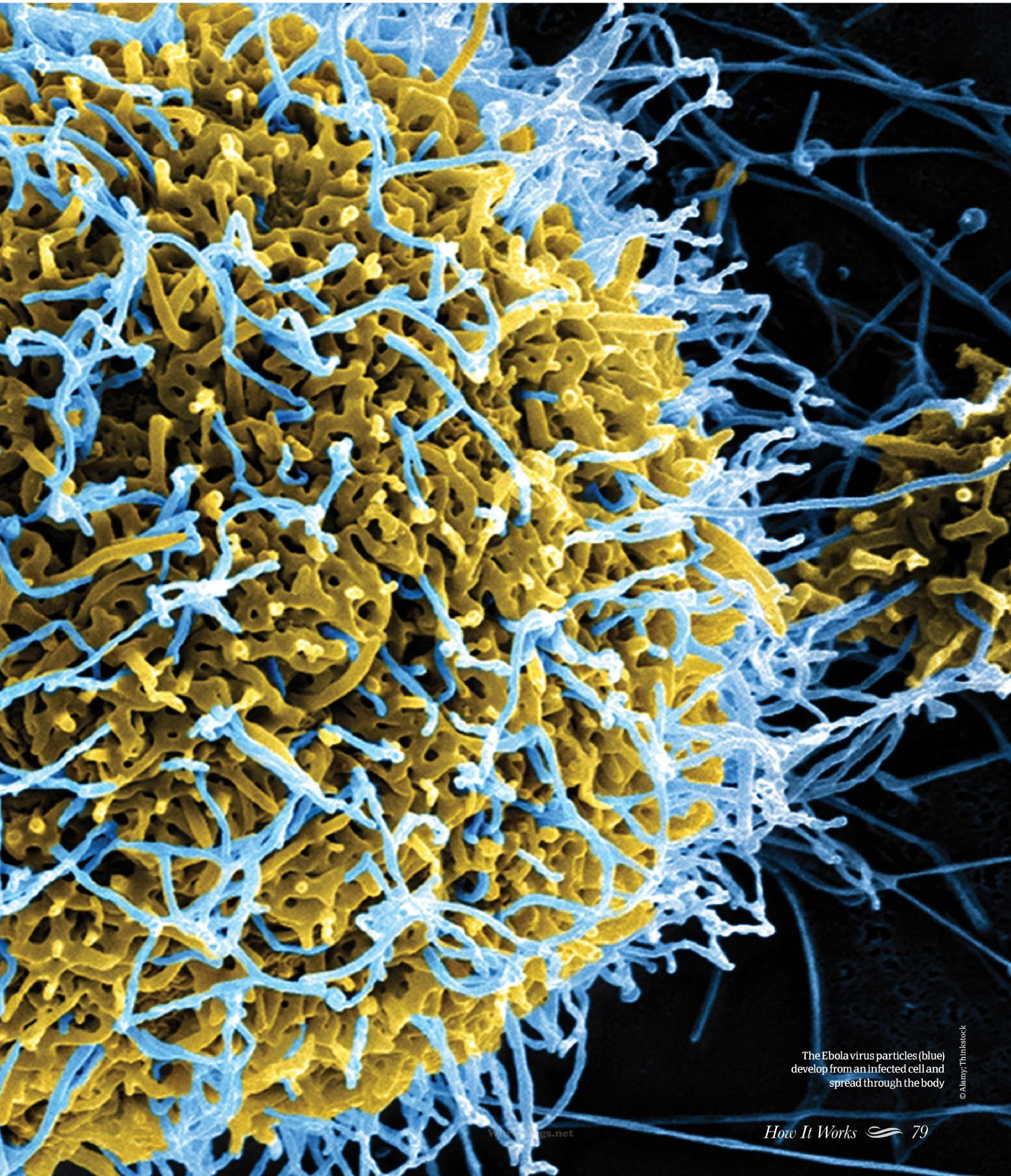
There have been many outbreaks since the disease first appeared in 1976, but the most recent has the highest death toll due to it spreading to vastly populated urban areas instead of being contained in rural villages.

There is currently no licensed treatment for Ebola, but there are potential vaccines currently being developed and tested. However, the chances of survival are significantly improved if the body is quickly rehydrated, buying more time for it to fight off infection. ✹

Why is Ebola so deadly?

Instead of being sphere-shaped, like most viruses, the Ebola virus is actually long and thin, giving it a larger surface area for attacking a larger number of cells. The virus is also covered in attachment proteins that bind to the receptor sites of human cells and release the virus's genetic material, allowing it to take over healthy human cells and replicate itself into new copies of the virus. Once it enters the body, it will first aim to disarm the immune system so that the white blood cells can't fight off the virus before it spreads quickly. As a haemorrhagic fever virus, the infected cells release proteins which cause blood to leak out of the vessels. This is what causes the most extreme and often fatal symptoms of Ebola, impaired kidney and liver function, a drop in blood pressure and internal and external bleeding.

The shape and structure of the Ebola virus makes it a particularly virulent one



The Ebola virus particles (blue) develop from an infected cell and spread through the body

© Alamy; Thinkstock

How is eye colour formed?

Discover the science behind the blues, browns, greens and greys of human eye colour

It was originally thought that eye colour was based on a single gene. The truth is that eye colour is actually determined by more than a dozen genes.

The proteins that make up the iris scatter blue light and the default eye colour is blue, but in most people, the iris is packed with protective pigment known as melanin. It comes in two forms, brown eumelanin, and red pheomelanin, and the ratio of one to the other influences the shade, from a light chestnut colour, to almost black.

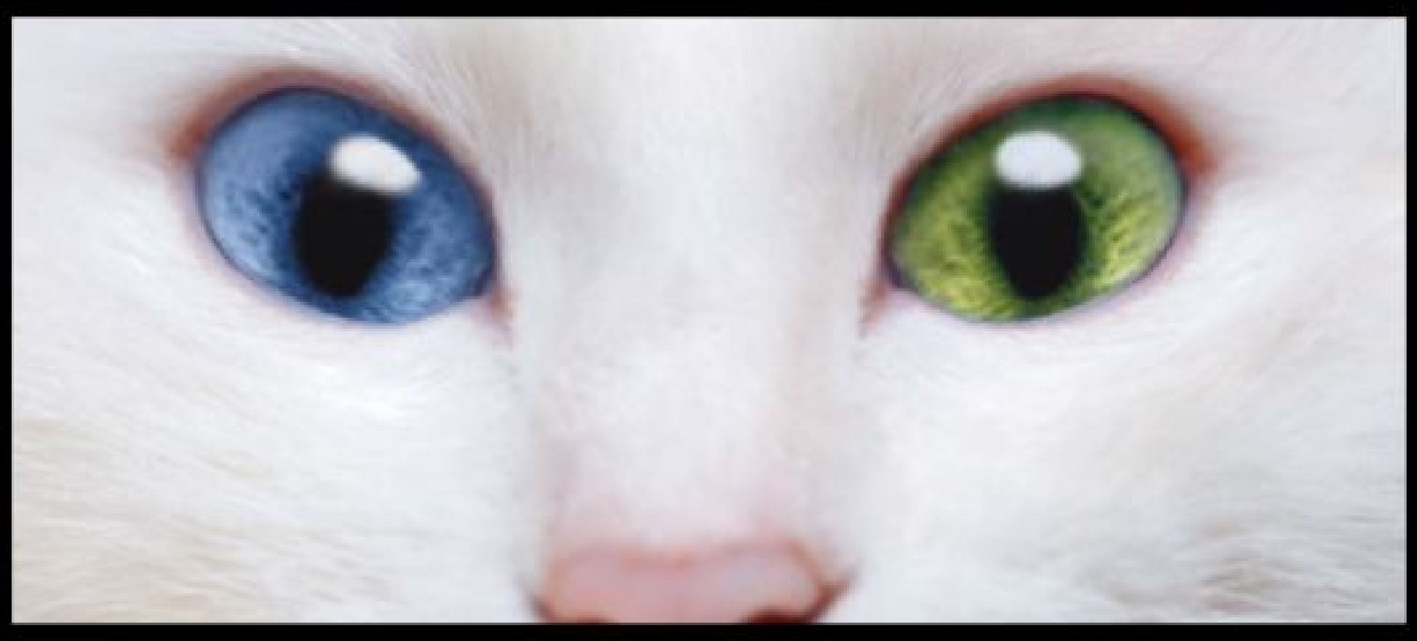
The bulk of the melanin production in the eye is controlled by two genes on chromosome 15, and if either one of these is faulty, very little pigment is deposited in the iris. Almost all people with blue eyes have mutations in one or both of these genes.

But what about other eye colours? In some people, the melanin production is not turned off, it is just turned down, and small amounts of pigment are still able to reach the eye. Sometimes the pigment covers the whole iris, resulting in green or hazel eyes, and other times it clumps together to form spots, stripes and rings around the pupil.

Spot the difference

Not only is there huge variation in eye colour in the human population as a whole, but some people also have amazing variation in their own eyes. People with complete heterochromia have two different-coloured irises.

The trait is not inherited and is most often the result of random gene mutations, or sometimes physical injury, causing uneven distribution of melanin. Heterochromia is quite rare in humans, but common in dogs, cats and horses.



What is dry ice and how is it produced?

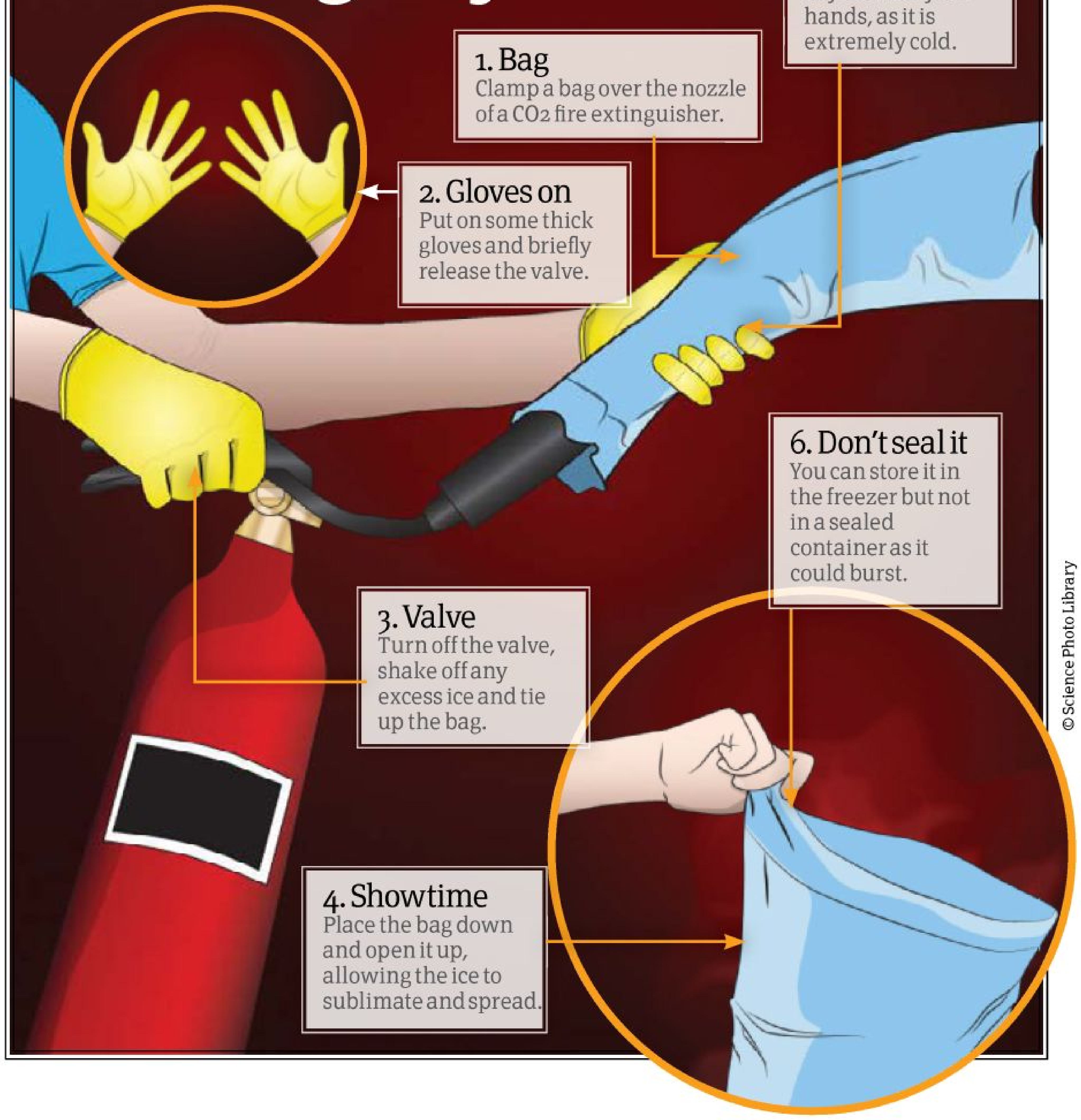
How do rock stars and actors get their atmospheric assistance?

If you've ever been to any kind of stage show, there's a chance you'll have seen dry ice being used. This is the stuff that's pumped onto the stage to simulate mist, or generally make the place look awesome, but what is it and how is it made?

Dry ice is actually highly pressurised liquid-carbon dioxide that has been frozen to a temperature of -78.5 degrees Celsius. The main benefit of using carbon dioxide is that when it warms up it sublimates, which means it changes from solid to gas without becoming a liquid. If you warm it up and pump it across a stage, it will turn instantly to cool-looking mist, rather than liquid.

It is really useful for packing frozen goods that need to stay cool because when it warms up, it turns gaseous.

Making dry ice



1. Bag
Clamp a bag over the nozzle of a CO2 fire extinguisher.

2. Gloves on
Put on some thick gloves and briefly release the valve.

3. Valve
Turn off the valve, shake off any excess ice and tie up the bag.

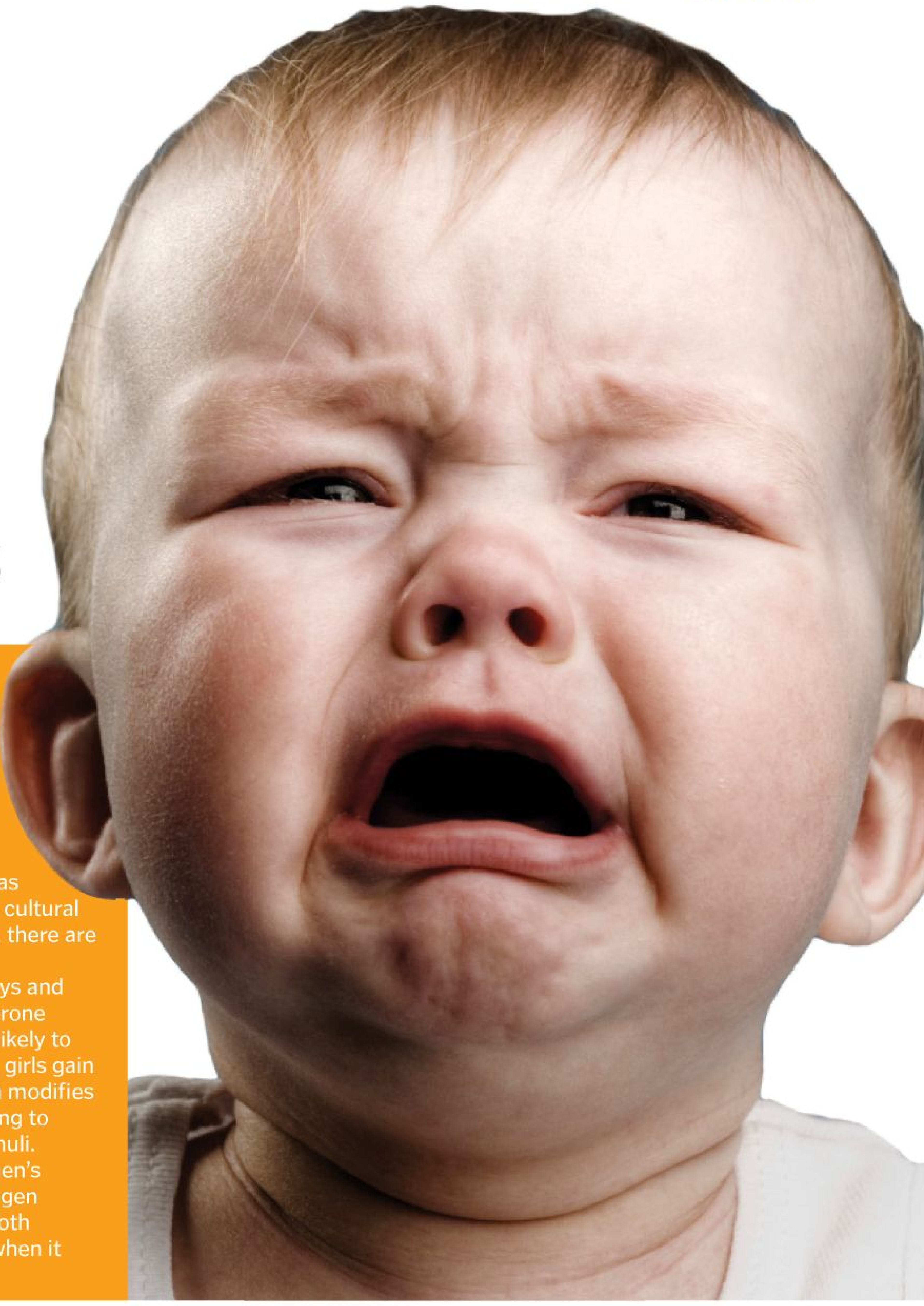
4. Showtime
Place the bag down and open it up, allowing the ice to sublimate and spread.

5. Hands off
Never touch solid dry ice with your hands, as it is extremely cold.

6. Don't seal it
You can store it in the freezer but not in a sealed container as it could burst.

© Science Photo Library

Why do we cry?



Find out how our tears have been helping to protect us since the dawn of time

Whether it's a sad film, a joyous reunion or simply that you've just banged your knee on the coffee table, everyone has cried at some point in their life. But why have we evolved to do it?

There's a theory that it stems right back as far as our pre-evolved days, where tears streaming down our primitive eyes and blurring our vision was a sign of surrender, proving that we meant our aggressor no harm.

But moving on to the present day, the science shows that there are a number of sound biological reasons for tearing up.

There are reflex tears, the stream caused by getting smoke or sulphenic acid from a chopped onion into your eye. When this happens, sensory nerves in your cornea send a signal to the brain that the eyes need protecting. The brain then releases hormones into the lacrimal glands located behind the eyelid, which produces tears to provide a layer of protection and to water down the irritant.

However, the more common form of crying is the emotional kind. When strong emotions are brought about, the brain's cerebrum is aware that you are undergoing a strong emotional reaction to a stimulus. The endocrine system releases a set of hormones to the lacrimal gland, which secretes liquid onto the eye.

Studies of tears have shown that there is a biochemical reason for emotional crying. While reflex tears are 98 per cent water, emotional tears contain several chemicals, including adrenocorticotropic hormones present in times of stress, and leucine-enkephalin, which is an endorphin that releases pain and improves your mood. Therefore, crying appears to be a way of releasing hormones and toxins that build up during times of intense emotion.

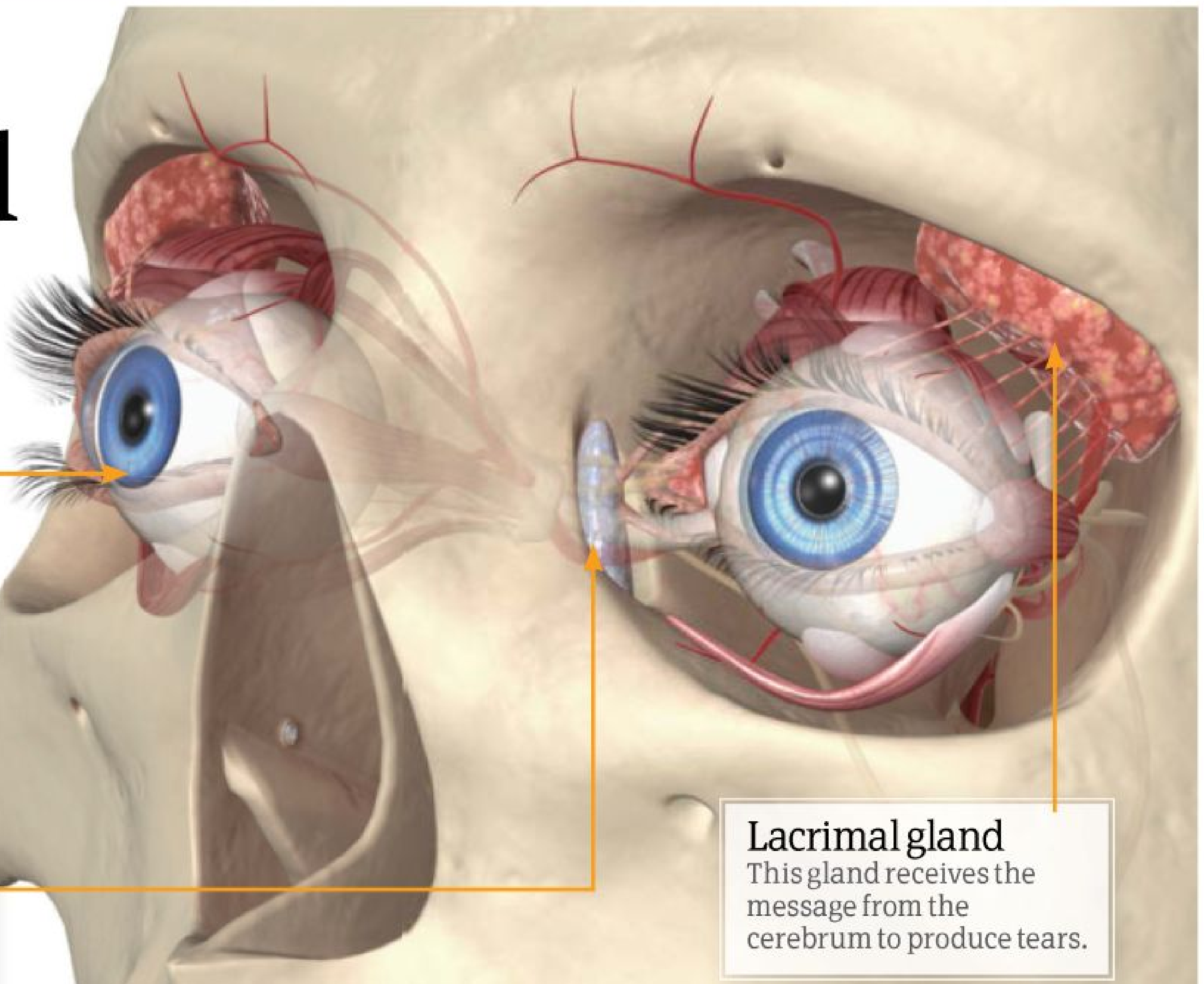
Battle of the sexes

While there is a stereotype that women are tearier than men, there is some science to explain the reasons behind this. Studies show that women cry four times as often as men and, while there are cultural factors to take into consideration, there are biological factors too.

Until their adolescent years, boys and girls cry fairly equally. As testosterone levels rise in boys, they are more likely to get angry than upset. Meanwhile, girls gain increased oestrogen levels, which modifies endorphin production, often leading to more emotional responses to stimuli.

But approaching middle age, men's testosterone and women's oestrogen balance out, once again putting both genders on a more even footing when it comes to crying.

The lacrimal system



Cornea
Tears help protect the surface of the eye.

Tear ducts
This is where the water flows to. If there's too much, it flows down the face.

Lacrimal gland
This gland receives the message from the cerebrum to produce tears.

What is zero-g?

Learn about the physics behind weightlessness and how it affects the human body in space

Also known as weightlessness, zero gravity is experienced in space stations and satellites, as well as for short periods in vacuum shafts and aircraft on a certain flight path (see the boxout below).

The term 'zero gravity' is actually misleading and is more appropriately called microgravity as the force is prevalent throughout the universe, albeit to varying degrees. For example, it is what keeps the Moon orbiting our world, and the reason Earth and all the other planets circle the Sun. Remarkably, on board the International Space Station (ISS) gravity is only around ten per cent weaker than on Earth.

While it may seem as if astronauts and objects have become so light they are floating, their mass is no different than when on terra firma. Essentially, they are all in a synchronised state of freefall – where the only force acting on them is gravity. Like the space station itself, everything in Low Earth Orbit (LEO) is falling around our planet at an equal rate, drawn by Earth's gravitational pull. In fact, every object is on its own individual orbit (just like the Moon) – hence why these physics apply whether someone is inside a space station or outside during a spacewalk.

A good way to grasp how weightlessness works is by imagining yourself in an elevator. As the lift travels down we experience a tiny reduction in weight, as the car is moving with gravity, while going up we gain what is called 'apparent weight' because of the additional force exerted by the floor accelerating against gravity. Should the lift cable snap, gravity will be the only force at play. As a result, both you and the car will fall at the same rate – 9.8 metres (32.2 feet) per second squared – so for the duration of the drop, you would 'float' in midair.

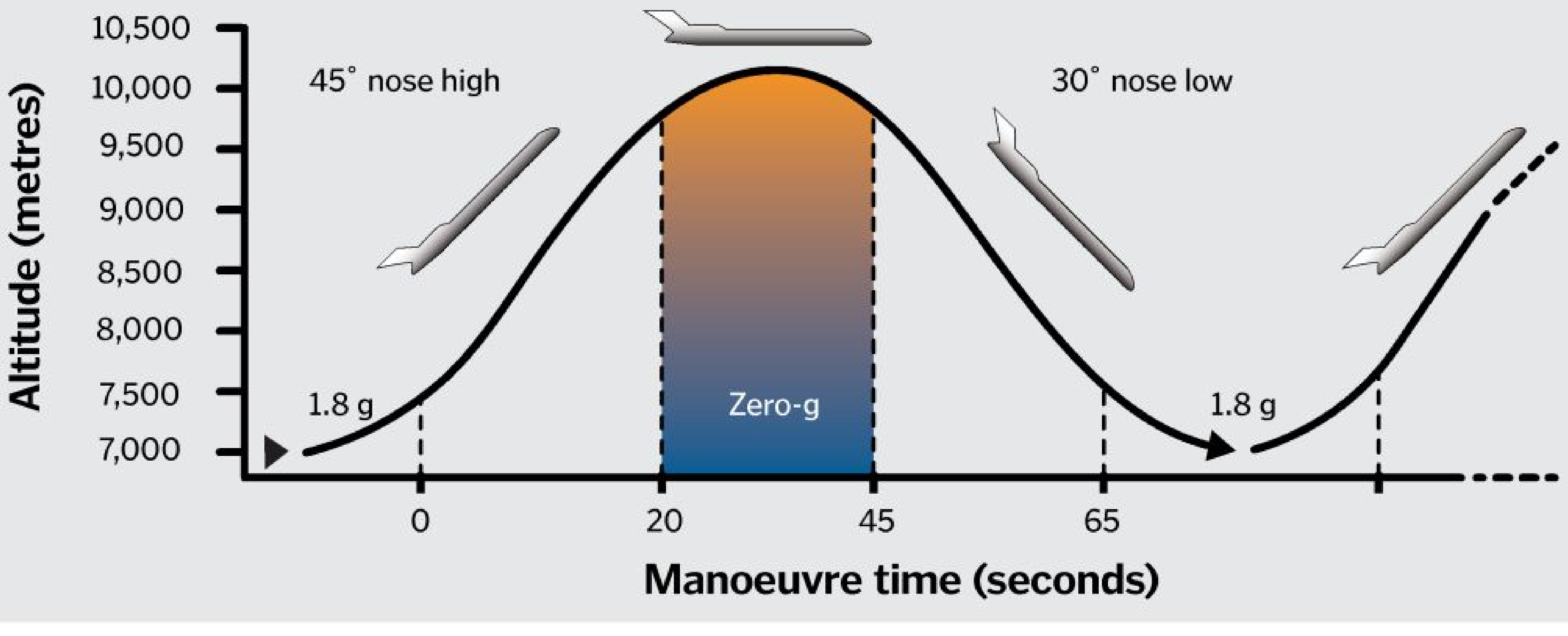
Handily for astronauts in training, there are ways to re-create the sensation of weightlessness here on Earth. NASA boasts the most advanced technology, which involves a vacuum-pumping process that lowers the pressure inside a building so objects can freefall for just over five seconds.

Theories suggest it takes the human body around 40 days to adjust to microgravity, which explains the frequent feelings of nausea when exposed to weightlessness.

In this state, many changes occur to the body. Among other things, there has been reported weakness, loss of balance and, most severely, a reduction in bone calcium. This raises concerns over how long humans can spend outside Earth's atmosphere and scientists continue to scrutinise all astronauts returning from missions for any physical damage.

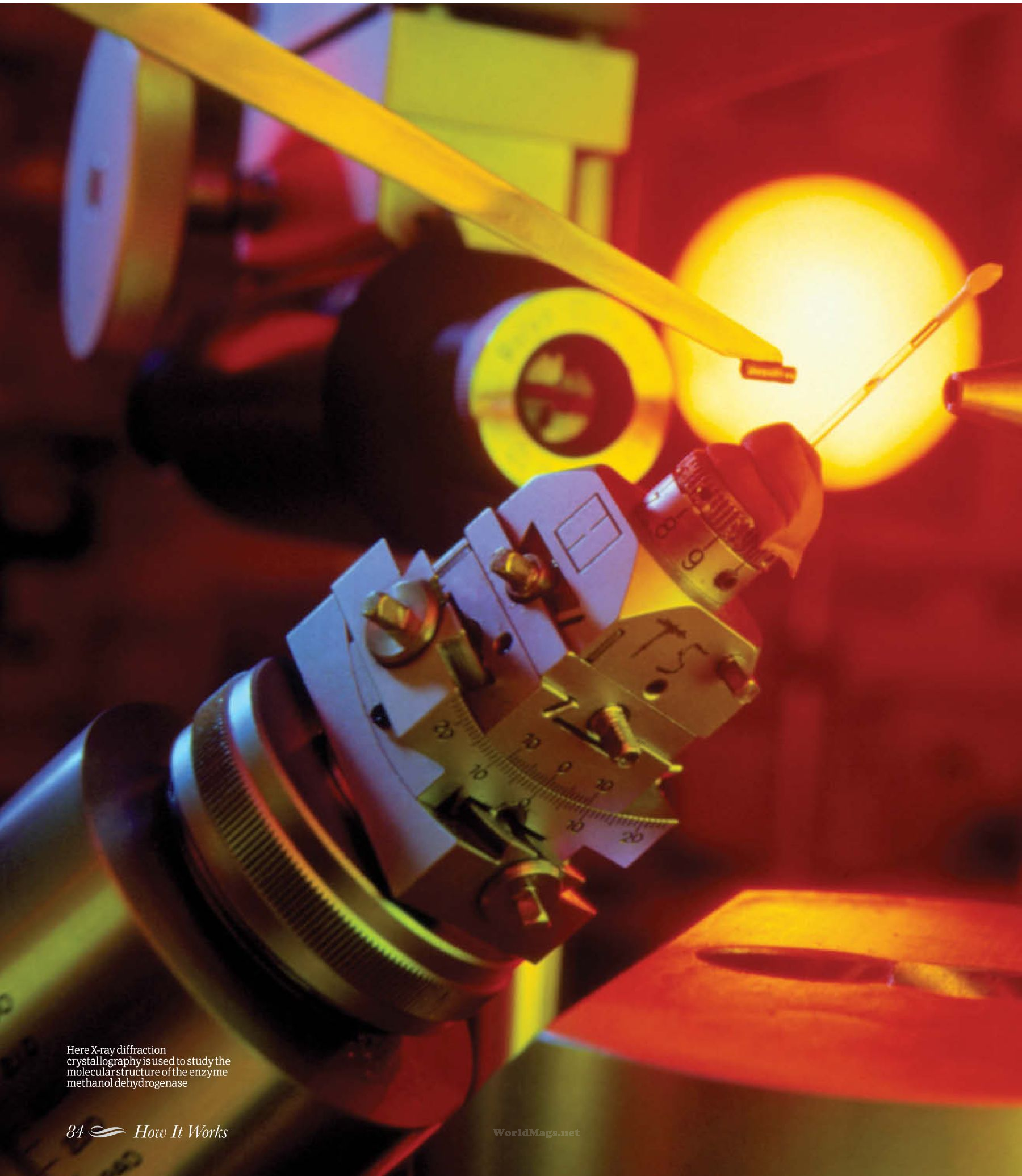
Re-creating weightlessness on a plane

Described as 'a space adventure open to the public', the G-Force One plane operated by the Zero Gravity Corporation goes through 15 parabolic arcs during its journey between 7,300-10,360m (24,000-34,000ft). Passengers experience 1.8 times their own weight in gravity at the start of the climb but are then shifted to microgravity and weightlessness at the arc's peak. This is the effect of centrifugal force being exerted on the plane but the zero-g periods only last for about 25 seconds.



Dutch ESA astronaut Andre Kuipers watches a water blob float freely aboard the ISS. In the reduced gravity environment, surface tension is the dominant force

© Alamy



Here X-ray diffraction crystallography is used to study the molecular structure of the enzyme methanol dehydrogenase

Can we understand crystals?

Crystallography sure gets a lot of buzz, but what exactly is it?

Crystallography is the analysis of crystals, used to increase our understanding of internal atomic structures – not just of minerals but of any substance which can be crystallised.

The practice is centred on the unique geometry of a crystal. First theorised by French physicist Auguste Bravais, all of a substance's angles are measured to find a crystal or lattice system. Co-ordinates are plotted to determine any symmetry, which can then define the atomic structure.

X-ray crystallography was popularised by German physicist Max von Laue in 1912, who showed crystals could be diffracted by this method. Atoms within the crystal diffract the X-rays and the angles of the deflection are measured. Scientists can then map a material's inner structure in great detail.

This technique can be used to determine the structure of organic substances such as proteins and DNA, as well as vitamins, alloys and other composite materials.

The rise of crystallography has paved the way to understanding atomic structure and bonding across many scientific fields like never before, though this technique remains relatively unknown. This is why the UN has declared 2014 as the International Year of Crystallography in order to raise its profile.

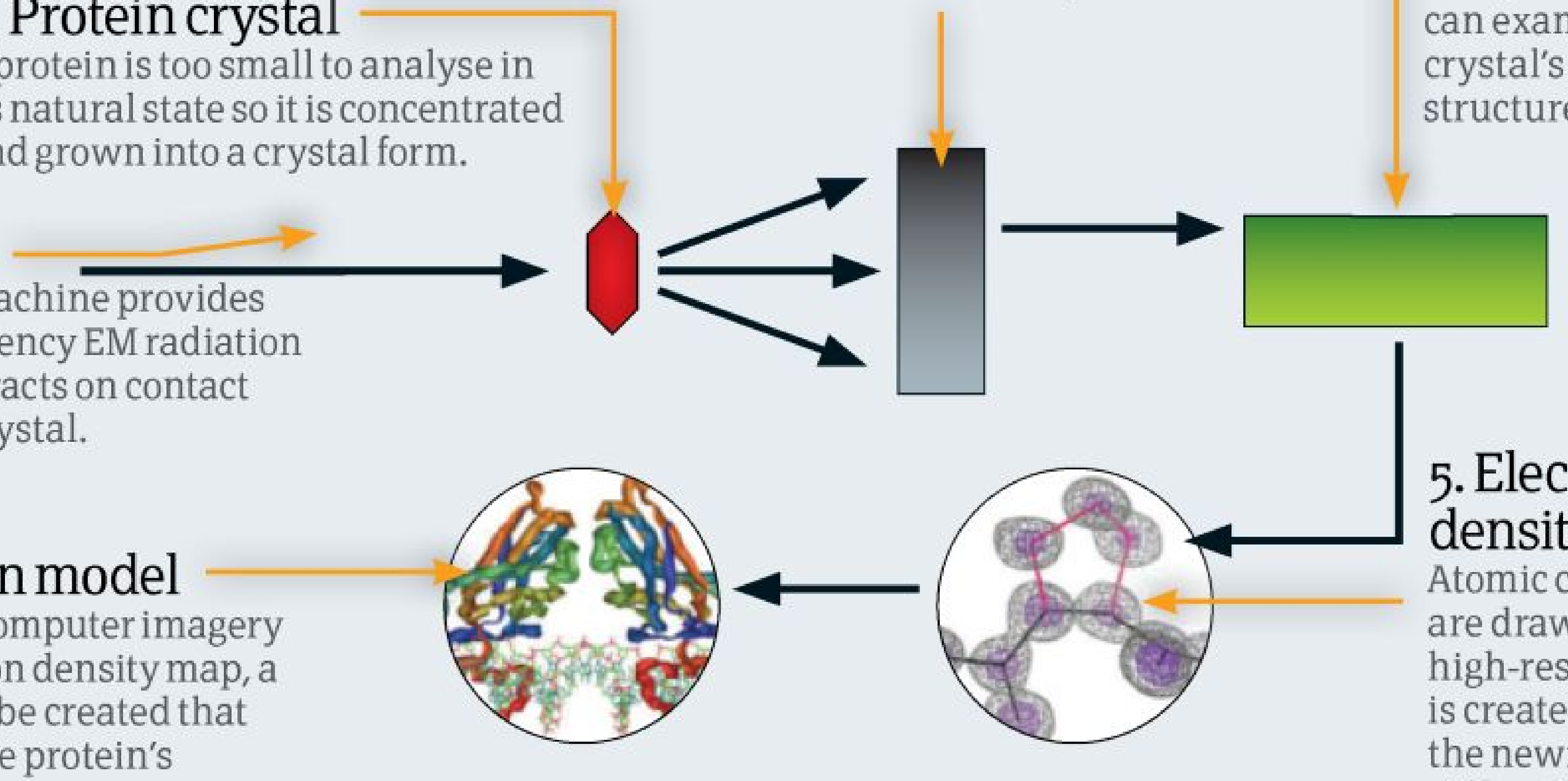
The origins of X-ray crystallography

The practice is thought to have originated from the work of Max von Laue. The German physicist worked in universities across the country, under the guidance of famous scientists Max Planck and Albert Einstein. He discovered the diffraction of X-rays through the atoms of a crystal in 1912. His results were developed with the help of physicists Paul Knipping and Walter Friedrich and demonstrated the period arrays of atoms in crystals.

Englishman William Bragg and his son Lawrence built on Von Laue's work to create an X-ray spectrometer that analysed the molecular structure of crystals, showing the relative positions of atoms in crystals. Von Laue and the Braggs received the Nobel Prize for Physics in 1914 and 1915, respectively.

Mapping out a protein

How crystallography unlocks our microbiology



1. X-rays
An X-ray machine provides high-frequency EM radiation which diffracts on contact with the crystal.

2. Protein crystal
A protein is too small to analyse in its natural state so it is concentrated and grown into a crystal form.

3. Catching rays
A detector measures the properties of the rays and how they're distorted.

4. Make an image
The data is then uploaded to a computer so crystallographers can examine the crystal's molecular structure inside.

5. Electron density map
Atomic co-ordinates are drawn up and a high-resolution map is created showing the newfound diffraction pattern.

6. Protein model
From the computer imagery and electron density map, a model can be created that displays the protein's atomic structure.

© SPL

Will we ever cure deafness?

We're getting ever closer to restoring the gift of hearing

There are more than 250 million people in the world who suffer from hearing loss or deafness, but it seems there is hope for them now.

Humans are able to hear things thanks to thousands of tiny hairs just inside their ears that vibrate when sound waves hit them. Sensory hearing loss occurs when they die or become damaged, meaning that they are no longer able to perform that action. This usually happens when the ear has been subjected to loud noises or the hair no longer regrows, often due to old age or natural degeneration.

Fortunately, scientists have been working hard to reverse that process. A recent study by British scientists has found that there is a protein contained in the body called Notch that stops new ear hair cells growing from stem cells. They have developed a drug that blocks this protein, meaning the body can regrow those crucial ear hairs.

A second experiment carried out by the University of Kansas injected a harmless virus into the ears of patients, which had a gene called Atoh1 in it, which stimulated the growth of the sensory hairs.

While we are still an awfully long way from being able to cure deafness from birth, these recent developments mean that people who have steadily lost their hearing could soon have it back, as loud and clear as ever.

Help for hearing

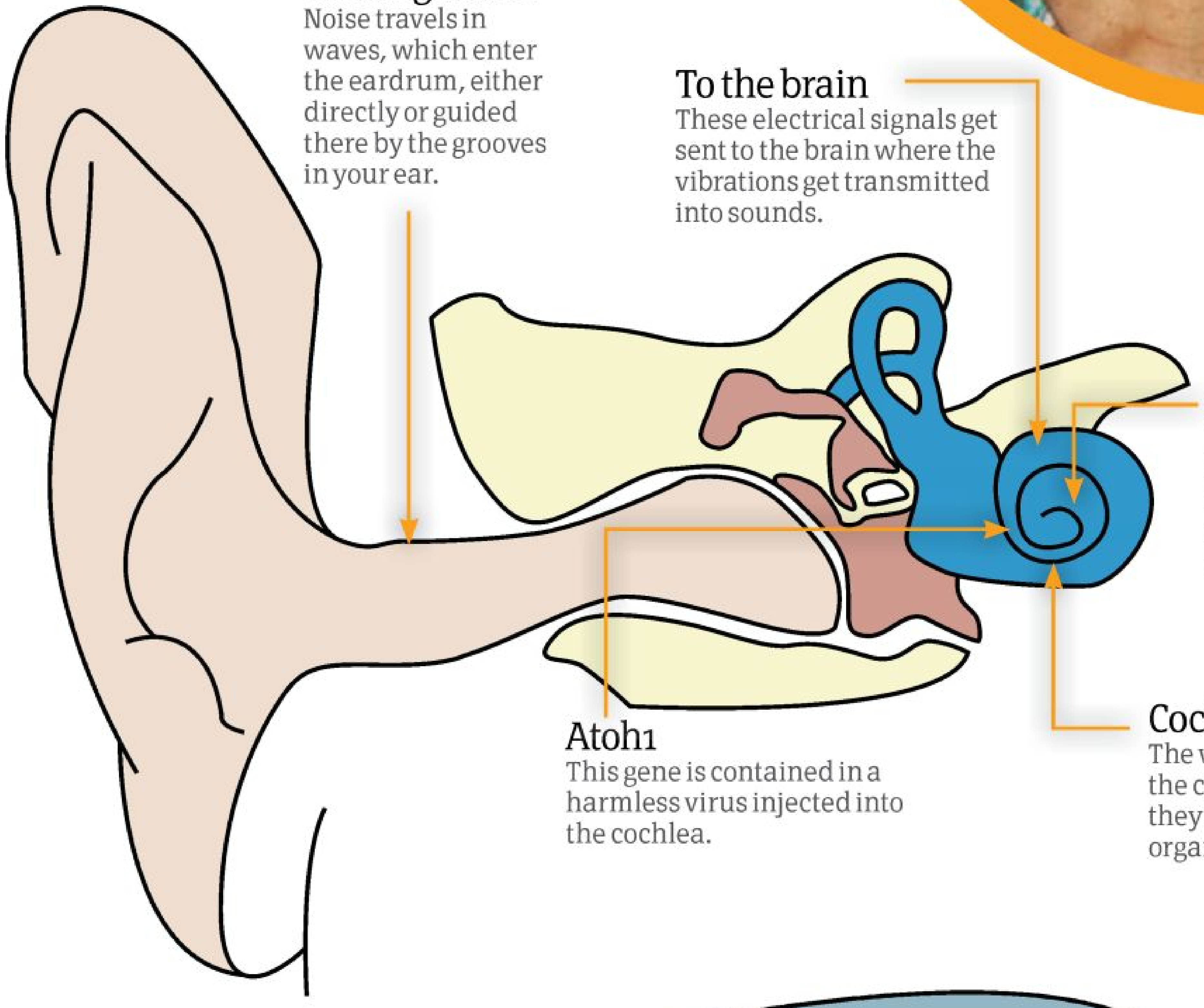
While the prospect of regrowing sensory hair cells and curing deafness is really exciting, there have been ways of helping people hear for a long while now. Ear trumpets were used in the 17th century as a popular way of helping people hear as they provided a much wider area for the sound waves to get trapped in.

Nowadays, digital hearing aids are the norm. They are placed in the ear and a receiver registers the sound wave. A silicon chip then converts the sound waves into electrical signals, which are then released into the ear. They are basically just a way of capturing sounds the ear wouldn't have heard otherwise.

Failing that, cupping your hand behind your ear gives you an extra 12 decibels of sound, so you can try that as a small temporary boost if you're in a loud room!

How ears work

How do our ears turn invisible waves into sound?



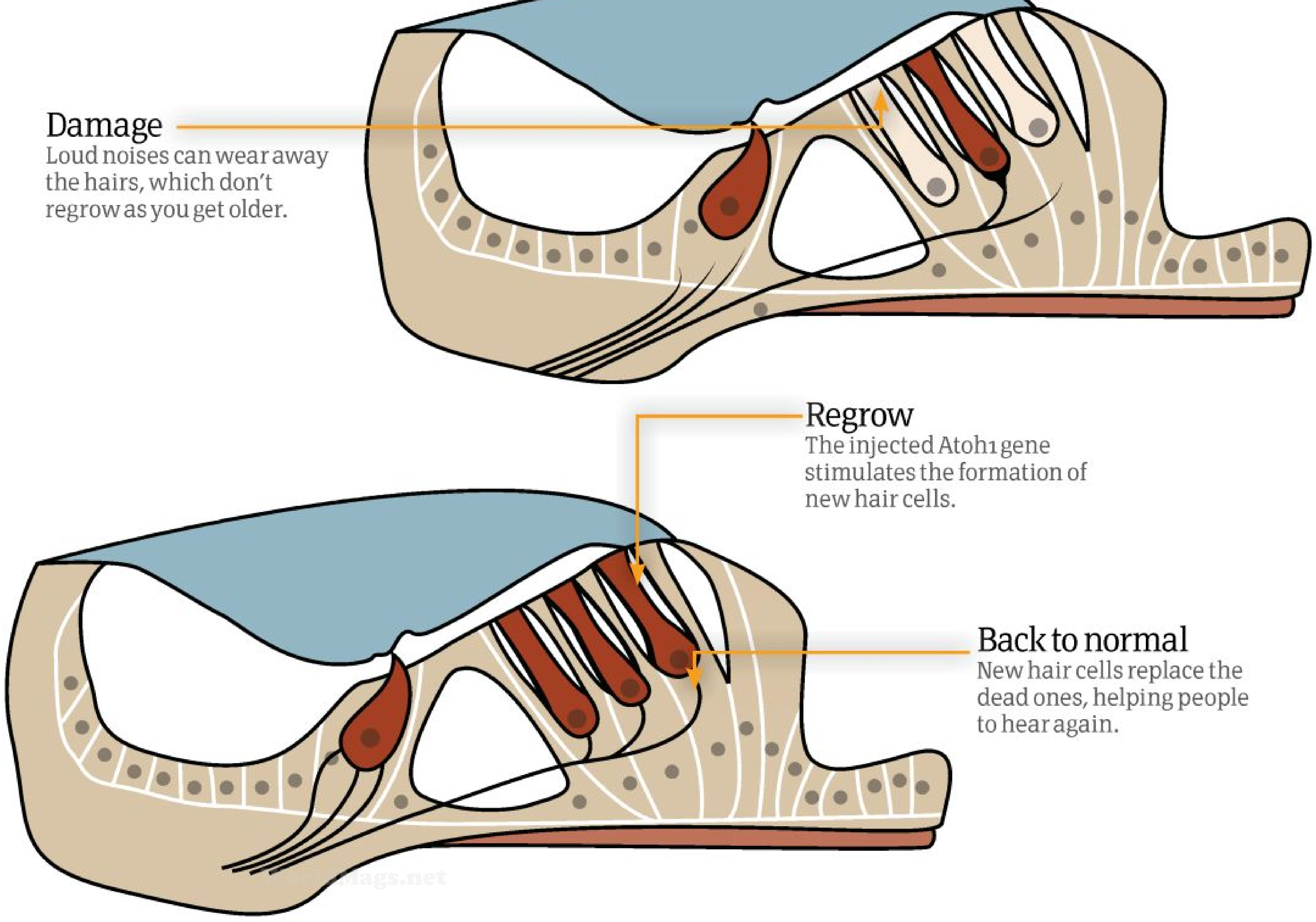
Making waves
Noise travels in waves, which enter the eardrum, either directly or guided there by the grooves in your ear.

To the brain
These electrical signals get sent to the brain where the vibrations get transmitted into sounds.

Organ of Corti
This tiny organ contains thousands of tiny hairs that sense the impulses and convert them into electrical signals.

Atoh1
This gene is contained in a harmless virus injected into the cochlea.

Cochlea
The waves move to the cochlea where they enter the organ of Corti.



Damage
Loud noises can wear away the hairs, which don't regrow as you get older.

Regrow
The injected Atoh1 gene stimulates the formation of new hair cells.

Back to normal
New hair cells replace the dead ones, helping people to hear again.

Why does a yo-yo spin?

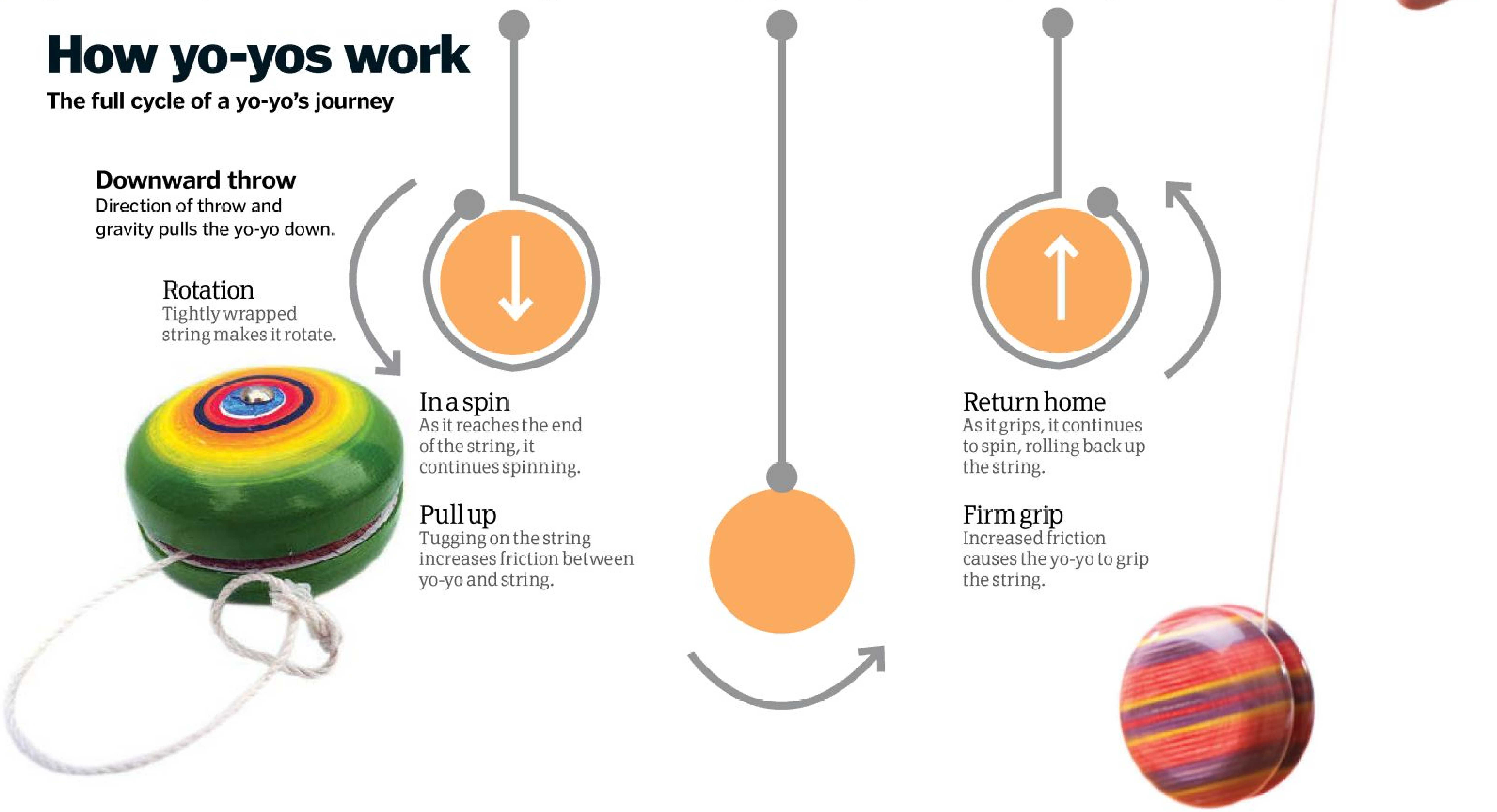
How we are able to 'sleep' and 'walk the dog' at the same time

The first part of how a yo-yo works is fairly easy to explain. A string is looped around the axle of a wheel and then wound around, making it look like a cotton reel. As you throw it out of your hand, it drops downward because of gravity and starts to spin as the string unravels around it.

But when it gets down to the bottom, gravity can't do any more work, but it continues to spin because of rotational energy. This is called 'sleeping.' A swift pull on the string increases the friction between the yo-yo and string. This makes it bite on the string and the rotations make the yo-yo wrap itself back up the string and climb back up.

How yo-yos work

The full cycle of a yo-yo's journey



Downward throw
Direction of throw and gravity pulls the yo-yo down.

Rotation
Tightly wrapped string makes it rotate.

In a spin
As it reaches the end of the string, it continues spinning.

Pull up
Tugging on the string increases friction between yo-yo and string.

Return home
As it grips, it continues to spin, rolling back up the string.

Firm grip
Increased friction causes the yo-yo to grip the string.

What is an ion?

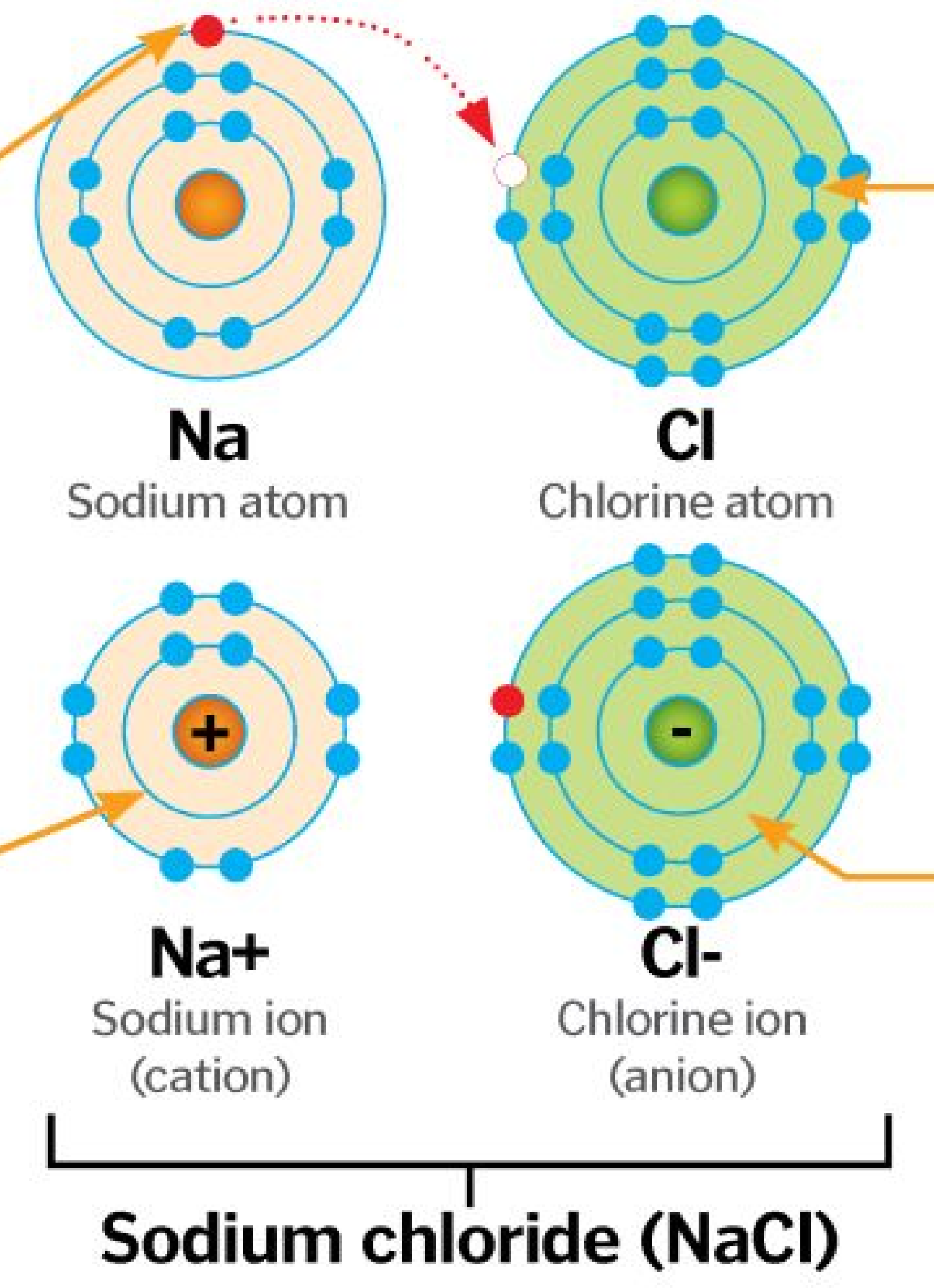
The electric science of charged atoms revealed

An ion is an atom or molecule that has an electric charge, which stems from an imbalance of electrons and protons. Extra electrons result in a negative charge while fewer result in a positive charge. The process of atoms turning to ions is called ionisation and occurs between metals and nonmetals. Metal atoms become positive ions and nonmetal atoms become negative ions. An example of ion-forming elements are sodium, chlorine and potassium. Sodium and potassium are metals while chlorine is a nonmetal.

Electrolysis can be used to separate ionic compounds back into their pure elements, where an electric current is passed through to divide the charged ions. This technique is especially useful for extracting precious metals, such as gold and silver, from their ores.

Salt in the making

What role do ions play in producing this popular seasoning?



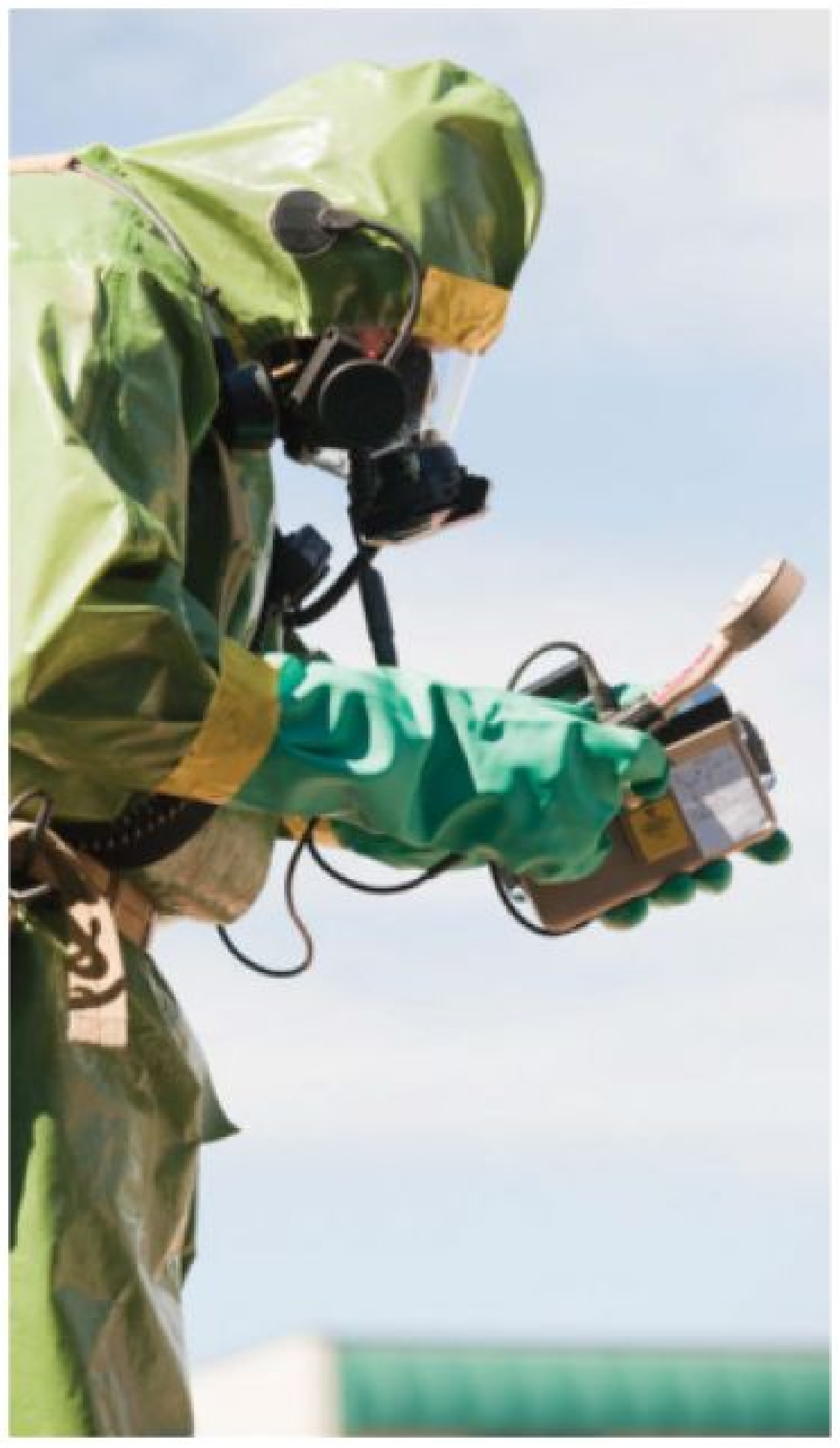
1. Loss
The sodium atom tries to lose an electron to make itself more stable.

2. Gain
The chlorine atom wants to gain an electron to make itself stable.

3. Ions
A sodium ion and a chloride ion are created. The opposite charges generate a strong ionic bond between atoms.

4. Salt
The result is the compound sodium chloride – or more commonly salt.

© Thinkstock



What is the most radioactive thing we encounter day to day?

Radon is a radioactive, colourless and odourless gas that is found all around us in very small amounts and is responsible for most of our daily dose of radiation. Radon gas a decay product of radium, which in turn is a decay product of uranium. Small amounts of uranium are found in the soil, with an average 2.6 square kilometres of surface soil containing about one gram of radium. Radon gas seeps into the atmosphere from the ground, where its primary way of entering the body is by inhalation. This doesn't pose a serious health risk, as levels are generally low. However, some places have higher concentrations of uranium, leading to dangerous buildups of radon gas, particularly inside homes. It's the second-biggest contributing factor toward lung cancer.

* * *

A bungee cord stretches under its own weight as it hangs

What are the physics involved with bungee jumping?

We are taught that everything falls towards Earth with the same acceleration of g = 9.8 metres (32.2 feet) per square second – ignoring air resistance. However, a bungee jumper often accelerates much faster than this. Of course, this depends on variables like the tension in the cord, as well as the weight of the cord and jumper. This phenomenon can be visualised by dropping a Slinky and a ball at the same time. Hold the Slinky, letting it hang but not touching the floor. The ball should be level with the top of the Slinky. Release both of them at the same time and watch as the top of the Slinky descends faster than the ball. The top of the Slinky not only accelerates due to gravity, but has a tension force from being stretched, also pulling down on it. A bungee cord stretches under its own weight as it hangs. So when someone jumps, they are pulled down not just by the force of gravity but by the tension in the cord as well.

Are there other 'funny bones' in the body?

The term 'funny bone' is misleading because it refers to the painful sensation you experience when you trap your ulnar nerve between the skin and the bones of the elbow joint. This happens in the so-called cubital tunnel, which directs the nerve over the elbow but has little padding to protect against external impacts. The ulnar nerve takes its name from the ulna bone, which is one of two bones that runs from the wrist to the elbow; the other is the radial bone, or radius. No other joint in the human skeleton combines these conditions and duplicates the this erroneously named reaction so we only have one 'funny bone'.

* * *

Is there any way to capture and use energy from lightning?

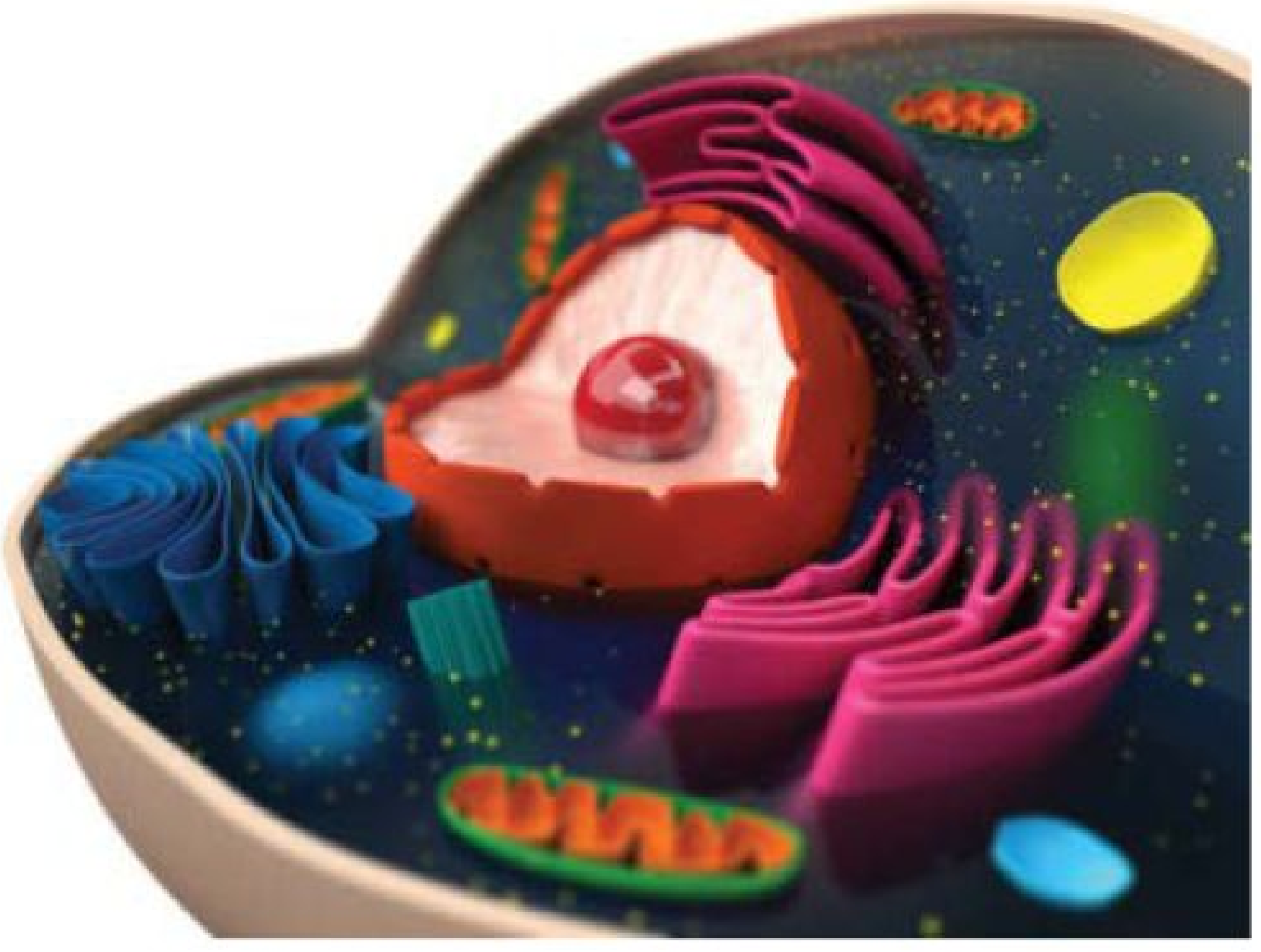
Deriving energy from lightning is problematic not least because you can't guarantee when and where strikes will occur. Furthermore, lightning bolts are literally gone in a flash so their energy would have to be captured instantly. Currently, no device can do that and developing one is not an appealing investment opportunity. One researcher claimed to have powered a light bulb with lightning when it zapped a giant capacitor connected to grounding wires, but that result has never been reproduced.

How does light therapy help people with SAD?

Seasonal affective disorder (SAD) is a form of depression associated with a lack of bright light. It can be most severe during autumn and winter when outdoor light is in reduced supply. Most indoor lights have been found to produce little or no benefit for sufferers and even increased exposure to sunlight is often ineffective. High-intensity light boxes have produced positive results, but it is not 100 per cent certain why. Researchers believe light stimulates mood-controlling chemicals in the brain, possibly in conjunction with the body's internal clock, which regulates hormone secretion and other functions such as sleep.

What is litmus paper?

Litmus paper is absorbent paper treated with litmus, a mixture of dyes which change colour with pH. One of many acid-base indicators, litmus reacts to concentrations of hydrogen ions (in other words, the pH), turning increasingly red under acidic conditions (below pH 7) or blue in basic conditions (above pH 7). The indicator molecule can exist in two different-coloured states: one associated with hydrogen, and the other not. In an acidic solution, excess hydrogen ions lead the red, hydrogen-associated form to dominate. Conversely, in a basic (alkaline) solution the equilibrium is shifted and the blue, the hydrogen disassociated form dominates.



What does a cell's cytoplasm do?

Cytoplasm is more than filler; it performs many critical biological functions in a cell. By definition, cytoplasm is all of the liquid inside a cell membrane but outside of the nucleus. Cytoplasm gives the cell its open, balloon-like shape through a scaffolding of microtubules and microfilaments, called cytoskeleton. Organelles also use microtubules as pathways to travel throughout the cell. In addition to water, cytoplasm contains enzymes that break down glucose into a substance digestible by mitochondria. Other enzymes dissolve cellular waste so it can be removed through the cell membrane.

How is denim made?

Denim is a tightly woven fabric of two different colours of cotton yarn, indigo (blue) and white. In textile manufacturing, denim is known as twill weave. In this type of weave, the indigo yarn runs top to bottom and the white runs side to side. The weaving equipment is programmed to weave the white under the indigo with an alternating pattern that creates the trademark diagonal blue lines on the denim surface and white lines on the back.

How will we produce plastic when oil runs out?

As the global oil supply dwindles over the coming decades, plastics manufacturers will turn to natural gas, biomass and recycling as the feedstock of the future. Today, just about every plastic product – from Tupperware to polyethylene carpet – is derived from petroleum, a non-renewable fossil fuel that will dry up. The plastics industry has already shifted to natural gas, a more abundant fossil fuel, for most polyethylene production. Biomass holds real promise as a renewable source of plastics. Crops like corn, sugarcane, beets and potatoes contain dextrose, which can be fermented to produce lactic acid. Lactic acid can then be converted into lactide. The resulting polylactic acid is now the world's most popular bioplastic, used widely in food packaging. Experts predict that we will eventually resort to mining old landfills in the search for recyclable plastics.

Is clumsiness a biological trait?

Mild clumsiness – such as tripping over shoelaces, bumping your elbow, etc – is not likely to be a biological or hereditary trait, but doctors do believe that severe clumsiness has genetic causes. Studies have shown that severe childhood clumsiness is often caused by a developmental disorder. Such children take far longer to reach developmental milestones like walking, running, etc. Occupational therapy works wonders in many cases. Severe clumsiness in adults can also be cause for concern. Symptoms like involuntary movements and an unsteady gait can be early signs of Huntington's disease, a hereditary degenerative brain disorder. Don't panic – often clumsiness is just poor co-ordination.

Why do some flights take less time in one direction than the other?

Flying east to west commonly takes longer than flying west to east, because a high-altitude wind called the jet stream blows from the west, slowing the aircraft down. The jet stream always blows in the same direction because of Earth's rotation. Warm air from the equator rises and moves north or south towards colder regions. Areas nearer the poles rotate slower than the equator. Air from the equator has the same 'fast' rotation speed around the planet as the equator, and as this air moves to regions where the ground beneath it rotates slower, it turns into a wind moving west to east.

* * *

Why do we sometimes get mouth ulcers?

Ulcers are small lesions usually triggered by physical damage to the inside of the mouth, for example biting your cheek accidentally, eating sharp food or brushing your teeth. They are very rarely contagious and usually heal within ten days. Recurrent ulcers have a variety of causes, the most common being stress and hormonal changes. In other cases, recurrent ulcers may be symptomatic of conditions including B12 or iron deficiencies, gastrointestinal diseases or immunosuppressant diseases such as HIV. Ulcers are sometimes triggered by sensitivity to certain foods including strawberries, almonds and coffee.

What are lithographs?

It's a printing technique where the picture is drawn onto a block of limestone with an oily paint or wax crayon. The stone is then dunked in a mixture of weak nitric acid, which reacts with the stone to create calcium nitrate on all the blank parts of the image. The thin layer of wax attracts oil-based printing ink, whereas the wet calcium nitrate repels it. You create prints by pressing paper against the stone plate. Lithography is still used by the printing industry but with modern systems.

* * *

Do mood rings work?

Mood rings change colour in response to changes in skin temperature. Proponents claim this can happen when shifts in emotional state cause blood vessels to carry blood closer to or further away from the skin's surface. These temperature changes are conducted through the base of the ring to liquid crystals inside and stimulate them to change shape. The crystals might reflect different wavelengths of light, causing the ring to change colour. Although mood rings can be said to work in this sense, they may also respond to other causes of change in temperature.

What were Stanhope viewers?

They were a modification of the Stanhope lens invented in the 18th century by Charles, the Third Earl Stanhope. It was rod-shaped and included two curved lenses. In the mid-19th century René Dagron adapted it for purposes of micro-photography. Dagron added a convex magnifying lens to one end of the cylinder and swapped the curved lens at the other end for a flat one. He sold it as a novelty item for viewing tiny photos within jewellery and souvenirs, which could otherwise be seen only through a microscope.

* * *

How do ionisation chambers work?

Ionisation chambers are gas-filled radiation detectors that use electric charges to determine radiation levels. Ionising radiation knocks electrons off atoms as they pass through materials. When atoms lose electrons, they become positively charged ions. Ionisation chambers consists of a gas with two conductors on either side. Radiation creates ions in the gas. A voltage is applied, causing positive charges to move to the negative conductor, and vice versa. The leftover charge on the conductors is measured and used to calculate how much ionisation took place.

How do sunglasses protect our eyes?

Lenses in sunglasses are tinted to filter out light of certain wavelengths, reducing the overall intensity of light hitting your eyes, while minimising glare – reflected ambient light that obscures your vision on a sunny day. Grey, green, brown or red are the most effective at minimising colour distortion the most – important for seeing clearly, especially while driving. Lenses are made from glass or plastic; both are materials that block parts of the UV light spectrum, while allowing visible light through. Therefore, just wearing normal glasses already offers some protection from potentially harmful UV rays.

How do lava lamps work?

Lava lamps exploit the relative densities of two liquids, fine-tuned so that one is very slightly denser than the other. One common pairing is water and a combination of paraffin wax, oil and perchloroethylene (PCE). At room temperature, the wax mixture is denser than the water, and rests at the bottom of the vessel. Flick the switch and a tungsten bulb underneath the vessel heats the wax, which expands and becomes less dense than the water, rising up. As it cools, its density increases and it sinks back down to the base, ready to repeat the cycle.

What do chemical engineers do?

Chemical engineers design the industrial processes that transform raw materials into the products we use every day. They find the most cost-effective, safe and environmentally friendly ways of producing anything from drugs to plastics. Chemical engineers usually fall into one of two broad categories: process engineers, who design, construct and operate plants, and product engineers, concerned with developing new materials and substances. They apply their knowledge to alter the physical and chemical properties of different substances and materials. A chemical engineer employed in the food industry might focus on applying heat transfer and fluid flow principles to the manufacture of foods. In the energy sector, the job could involve developing fuels from renewable sources or improving the safety of nuclear power stations.

How are old paintings restored?

Reversing the effects of ageing and damage on a painting is a delicate process that uses a variety of techniques. First, a cleaning solution is applied to remove dirt and deposits. Then the restorer identifies previous retouches, shown up under ultraviolet or infrared light, before carefully stripping away discoloured varnish and retouches. Any damage to the canvas or support structure is repaired. Mixed with a binder to form a putty, pigments are applied to areas where paint has been lost. These retouches may be removed with solvents that will not damage the original painting.

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Space

Is there another Earth?

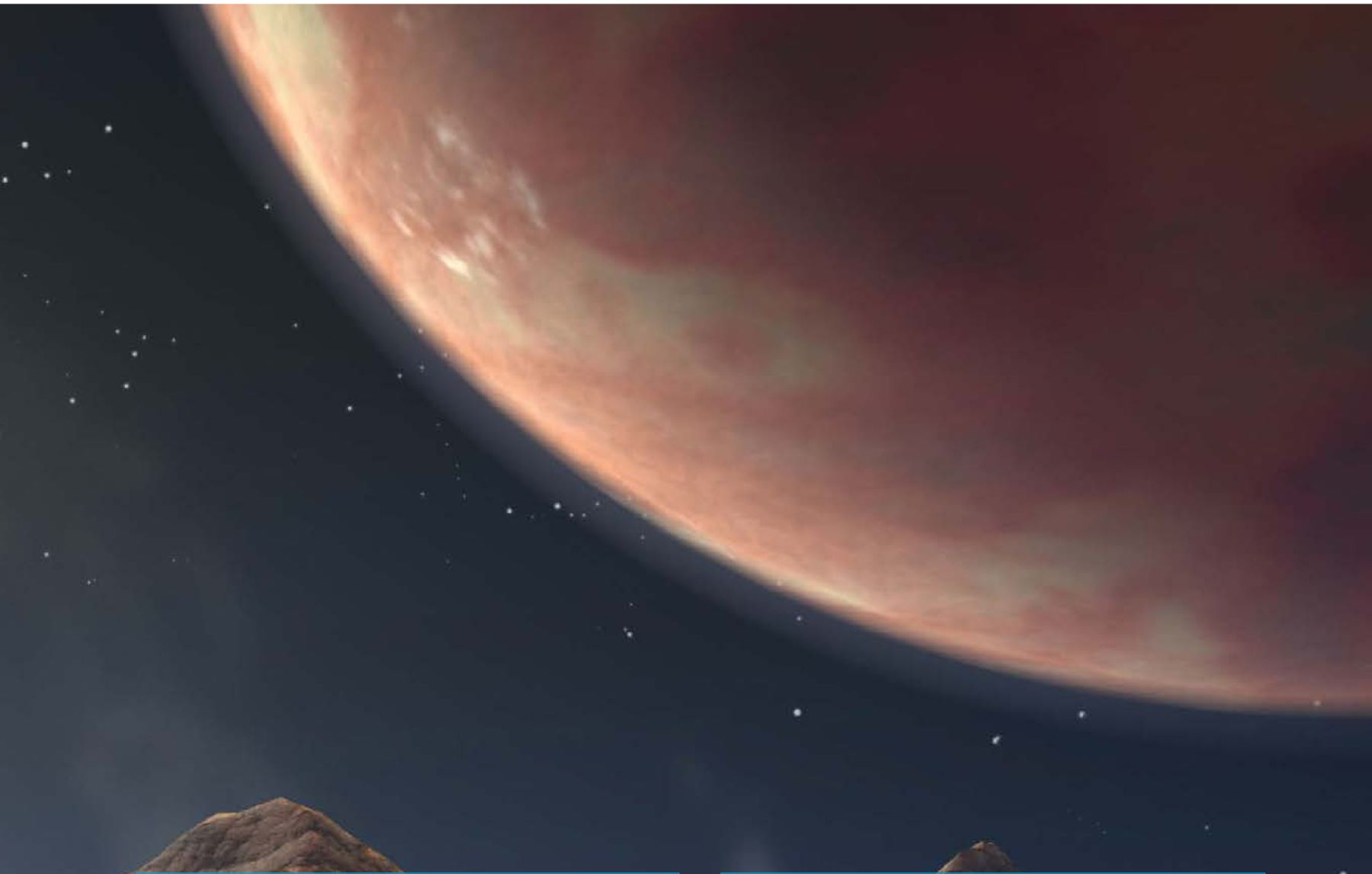
Discover the five strangest exoplanets ever found

To boldly go – in Star Trek the starship Enterprise would visit new planets every week from the Sixties onwards, but until 1995 we didn't even know whether planets around normal stars existed. Then astronomers found the first hot Jupiter, called 51 Pegasi b, which is a gas giant like our Jupiter, but extremely close to its star. That discovery opened the floodgates and today we know of over 1800 confirmed planets of all types – large and small, hot and cold, gas and ice.

To differentiate them from the planets of our familiar Solar System home, astronomers call these alien worlds extra-solar planets, or exoplanets for short. Of all these planets, less than two dozen have actually been photographed (and in the pictures they are just points of light). The others are detected through several methods, the two dominant ones called the radial velocity technique and the transit method. The former makes use of the gravitational interaction between a star and a planet – the star orbits the centre of mass between the star and planet, and so to us it appears to wobble, sometimes by just a few centimetres, but this causes its light to be Doppler shifted. The size of the Doppler shift and the period of the wobble tells us about the mass of the orbiting exoplanet and the size of its orbit.

Transits happen when a planet passes in front of its star. Our telescopes are not powerful enough to resolve the silhouette of the planet in front of its star, but we can detect the tiny dip in the star's light. The size of the dip, and the regularity with which the transits happen tell us the diameter of the planet and how far from its star it is. If astronomers are able to see a transit and measure the radial velocity, they can then measure both the mass and diameter of the planet, and calculate its density and work out whether it is rocky, gaseous or some mixture of the two.

Exoplanets are discovered with both ground-based telescopes and space-based telescopes, like the Kepler planet-finding satellite, and with a new wave of planet-finding space missions being built, as well as giant ground-based telescopes, we can expect to discover thousands more planets, and perhaps even the holy grail of a planet just like Earth. ✹



Just like earth: Exoplanet

One of the great quests is to find a planet that is like Earth and could support human life. Astronomers tend to categorise these planets as being found in the habitable zone, where temperatures are just right for liquid water on the surface. The best candidate so far is GJ 667Cc, which orbits a red dwarf in a triple star system. It is a super-earth, nearly four times the mass, and would be slightly hotter than Earth. It is unknown whether there is alien life.

This could be the view of the sunset on GJ 667Cc, with a triple sunset seen in this artist's impression

The statistics…

GJ 667Cc

Distance: 22.7 light years

Mass: 2.26 x 1025 kg (3.78 Earth masses)

Diameter: 22,425 km

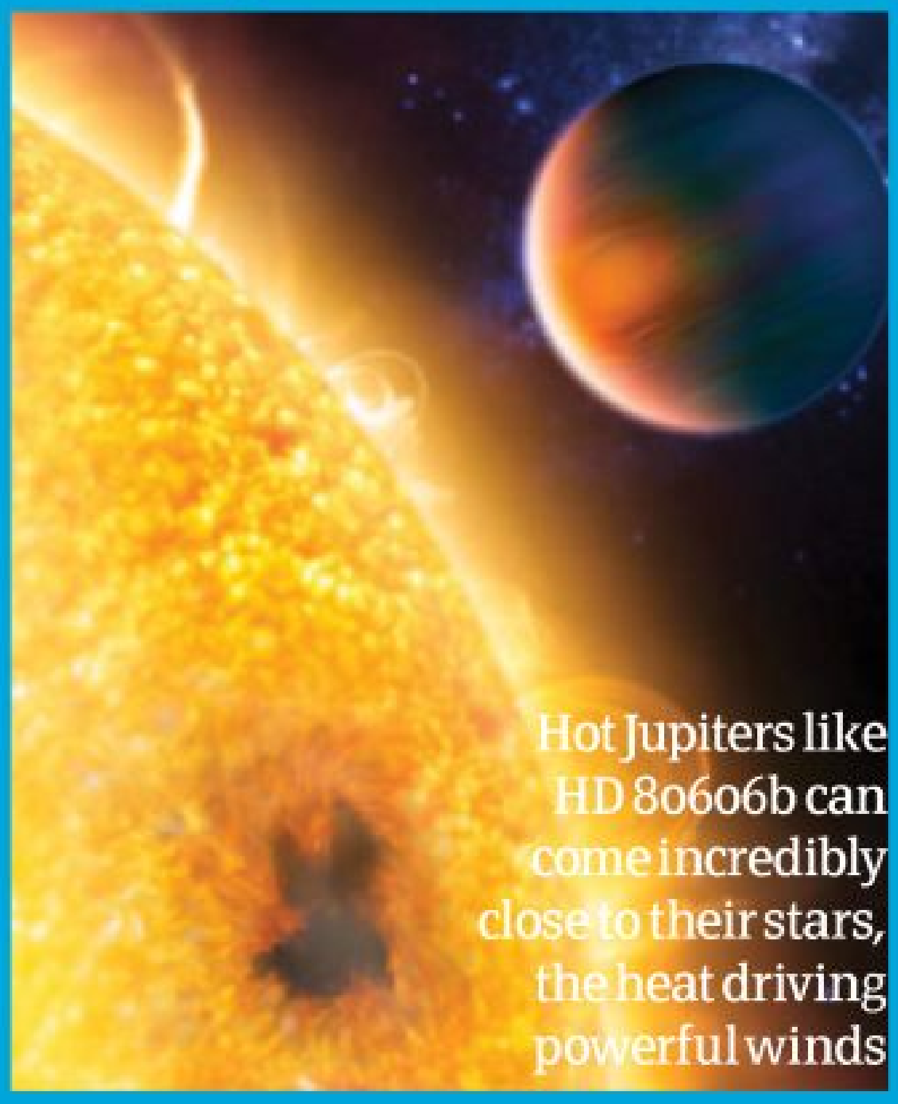
Length of year (orbital period): 28 Earth days

Discovered: 2012

Discovery method: Radial velocity

A planet-sized hurricane

The strongest winds ever measured on Earth was 408kph (253mph), but this was just a minor breeze compared to the winds measured on HD 80606b, which reach 10800mph (17380kph)! The reason for these winds is the planet's egg-shaped orbit, which at times brings it just 4.5 million km (2.8 million miles) from the Sun. This causes the atmosphere to heat up rapidly each time it comes close. This heat drives a superstorm in its atmosphere.



Hot Jupiters like HD 80606b can come incredibly close to their stars, the heat driving powerful winds

The statistics…

HD 80606b

Distance: 190 light years

Mass: 7.6 x 10^27kg (4 Jupiter masses)

Diameter: 128,776 km

Length of year (orbital period): 111 Earth days

Discovered: 2001

Discovery method: Radial velocity

The planet from hell

What happens though when a rocky planet finds itself in a similar situation to a hot Jupiter? CoRoT-7b is a molten world with a temperature between 1800 and 2600 degrees Celsius on its sun-facing side. It is tidally locked, so it always shows the same face to its star like the Moon does to Earth. The dayside's surface will be an ocean of lava, while the gravity from the nearby star will flex the planet's interior, causing the farside to be covered in giant volcanoes.

The statistics…

CoRoT-7b

Distance: 489 light years

Mass: 5-9 times the mass of Earth

Diameter: 20,132km

Length of year (orbital period): 20 hours

Discovered: 2009

Discovery method: Radial velocity

The surface of CoRoT-7b is so hot that the nearside of the planet has melted into an ocean of lava

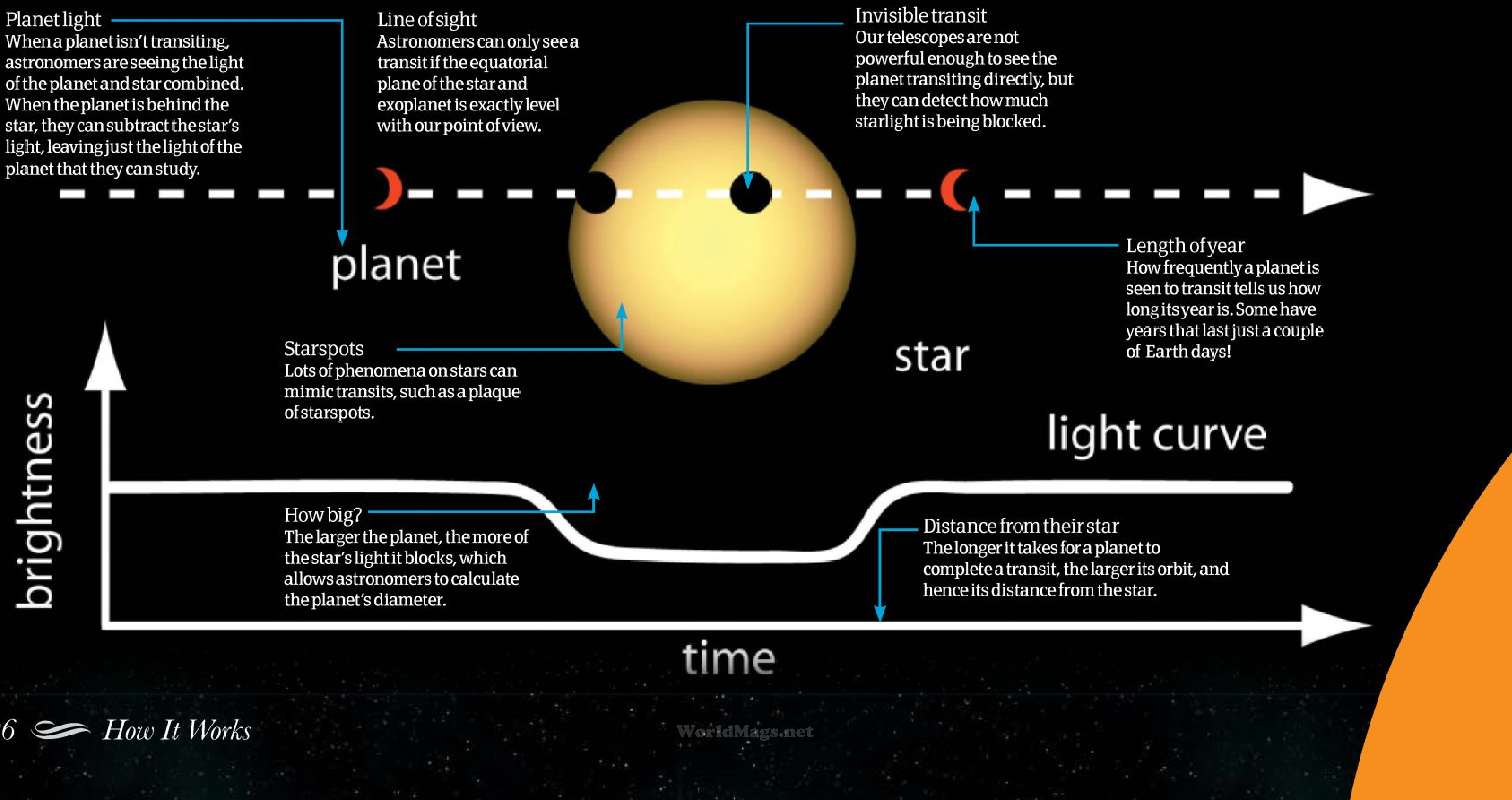
Big daddy of the planets

Besides the powerful winds, the heat that hot Jupiters receive warms their atmospheres so much that their atmospheres expand, increasing their diameters. When it was discovered, WASP-12b was the hottest planet known, with a temperature of 2250 degrees Celsius. Its expanding atmosphere, which increases the planet's diameter to 419,000 kilometres (257 million miles), is vulnerable to being torn away by the gravity of its sun at a rate of 189 quadrillion tonnes per year, which forms a large tail of gas, a bit like a comet. The gravitational tidal forces also distort the planet into an egg-shape. This is one very messed-up planet.

WASP-12b's expanded atmosphere is being torn away into a long tail that forms a disk around its star

Understanding exoplanet transits

The Kepler Space Telescope discovers planets by watching for their transits as they pass in front of their stars.



Planet light
When a planet isn't transiting, astronomers are seeing the light of the planet and star combined. When the planet is behind the star, they can subtract the star's light, leaving just the light of the planet that they can study.

Line of sight
Astronomers can only see a transit if the equatorial plane of the star and exoplanet is exactly level with our point of view.

Invisible transit
Our telescopes are not powerful enough to see the planet transiting directly, but they can detect how much starlight is being blocked.

Length of year
How frequently a planet is seen to transit tells us how long its year is. Some have years that last just a couple of Earth days!

Starspots
Lots of phenomena on stars can mimic transits, such as a plaque of starspots.

How big?
The larger the planet, the more of the star's light it blocks, which allows astronomers to calculate the planet's diameter.

Distance from their star
The longer it takes for a planet to complete a transit, the larger its orbit, and hence its distance from the star.

> "Its expanding atmosphere, which increases the planet's diameter to 419,000km, is torn away by its sun's gravity"

The statistics…

WASP-12b

Distance: 800 light years

Mass: 2.56 x 1027 (1.3 times mass of Jupiter)

Diameter: 255870km

Length of year (orbital period): 26 hours

Discovered: 2008

Discovery method: Radial velocity

A diamond in the rough

Astronomers tend to focus on the surfaces, or cloud tops of planets, but sometimes what lies beneath is even more interesting. The planet known as 55 Cancri e is a huge 'super-Earth'. It is dry, with no chemical signature of water, and it is rich in carbon, amounting to a third of the planet's mass. In its core, all this carbon will be compressed under high pressures, to the point that deep within 55 Cancri e there is quite possibly a giant core of diamond.

The statistics…

55 Cancri e

Distance: 41 light years

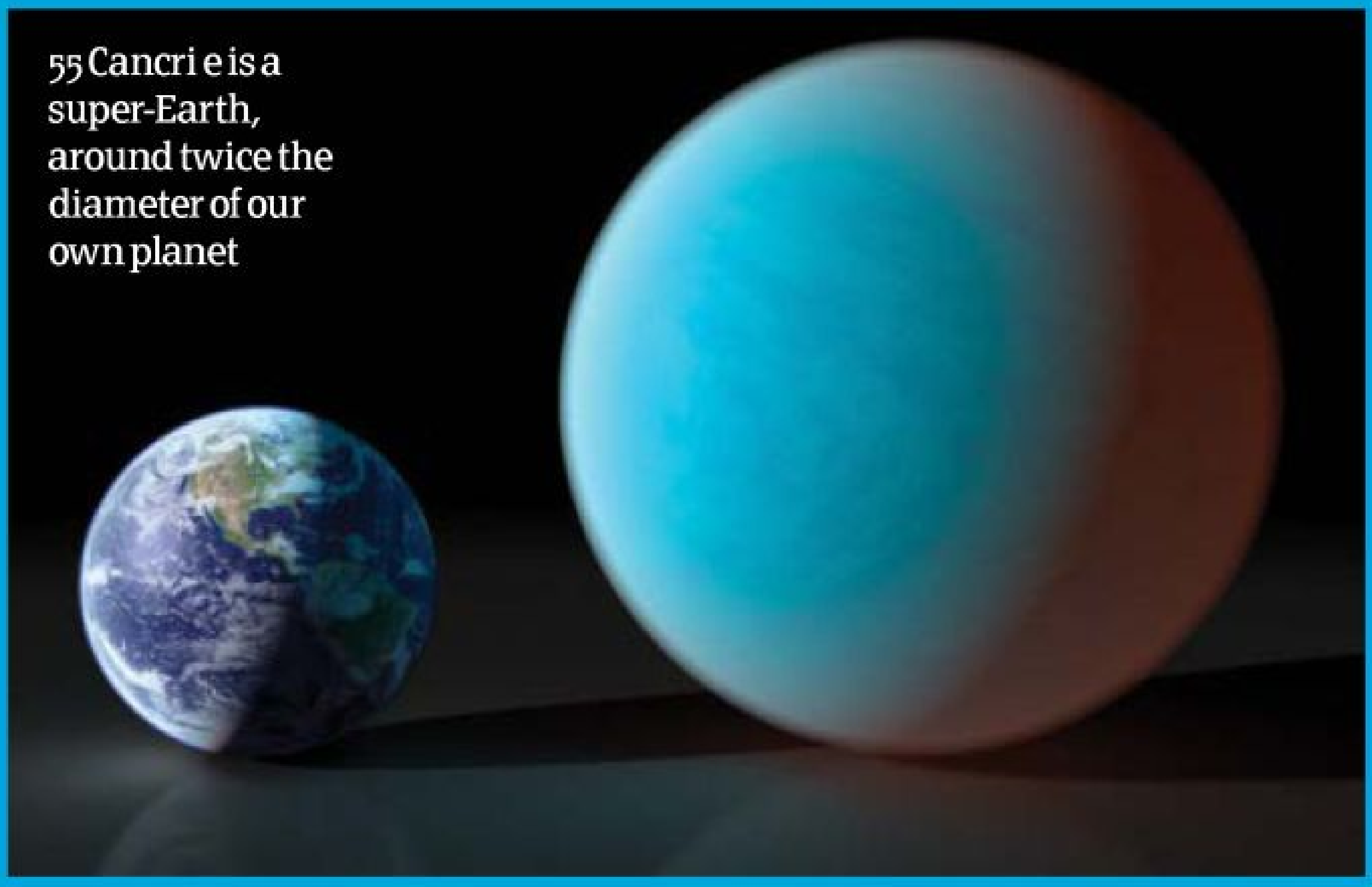
Mass: 4.7 x 1025kg (7.8 Earth masses)

Diameter: 24,000km

Length of year (orbital period): 17 hours

Discovered: 2004

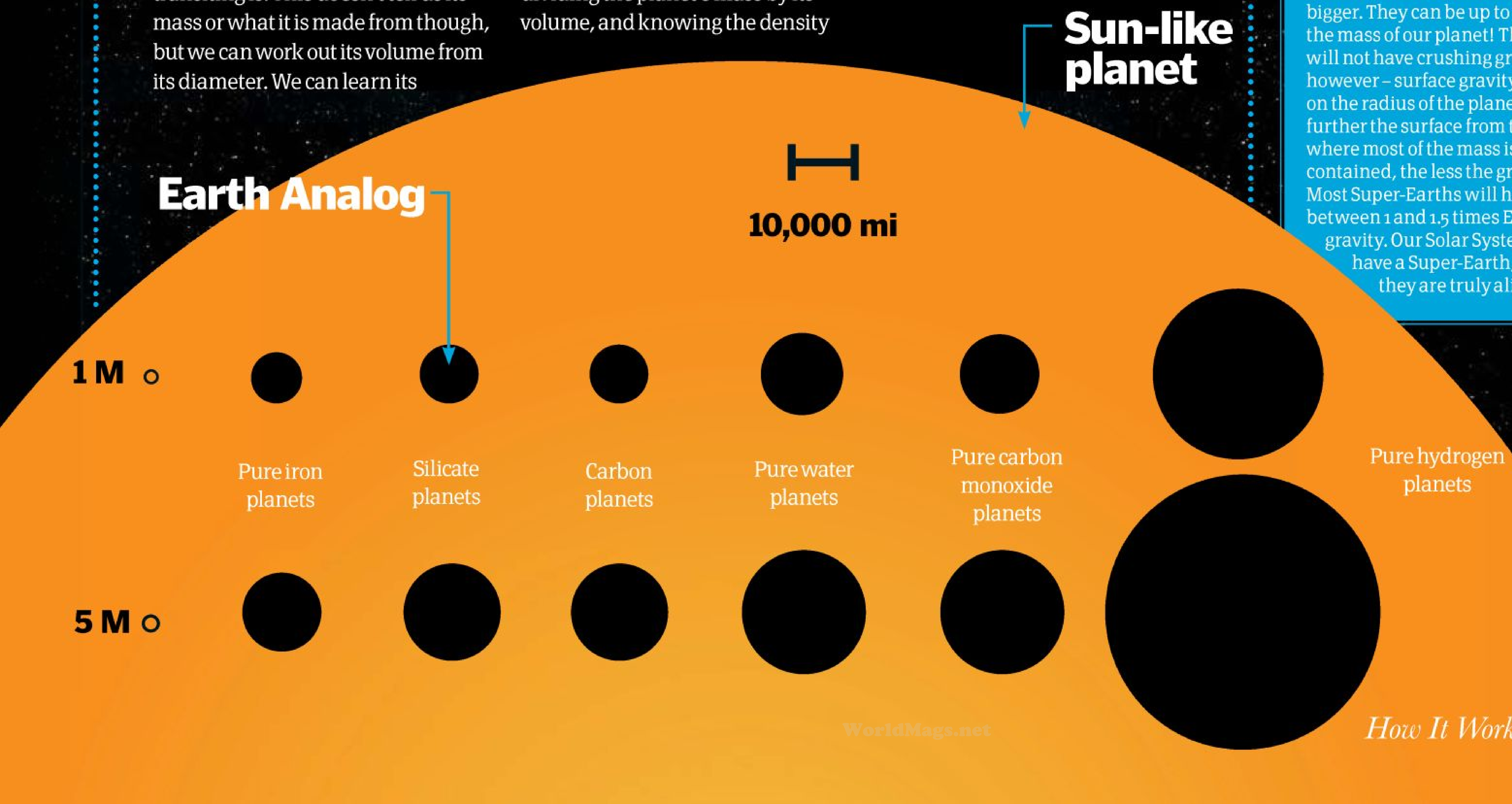
Discovery method: Radial velocity



55 Cancri e is a super-Earth, around twice the diameter of our own planet

Predicting the sizes of exoplanets

The size of a transit – in other words, how much star light is blocked – tells astronomers how big the planet transiting is. This doesn't tell us its mass or what it is made from though, but we can work out its volume from its diameter. We can learn its mass by seeing how much its gravity causes its star to 'wobble'. Density is calculated by dividing the planet's mass by its volume, and knowing the density astronomers can figure out whether the planet at hand is made of rock, gas or water.



Giant Super Earths

Super-Earths are rocky planets like Earth or Mars, but much, much bigger. They can be up to ten times the mass of our planet! These worlds will not have crushing gravity, however – surface gravity depends on the radius of the planet, and the further the surface from the core, where most of the mass is contained, the less the gravity is. Most Super-Earths will have gravity between 1 and 1.5 times Earth's gravity. Our Solar System does not have a Super-Earth, meaning they are truly alien planets.

© NASA; NASA/JPL-Caltech/R. Hurt (SSC).; NASA/ESA/G Bacon (STScI); NASA Ames; ESA/NASA/G Tinetti (UCL/ESA)/M Kornmesser (ESA/Hubble); ESO/L Calçada

What happens at the ELS launch pad site?

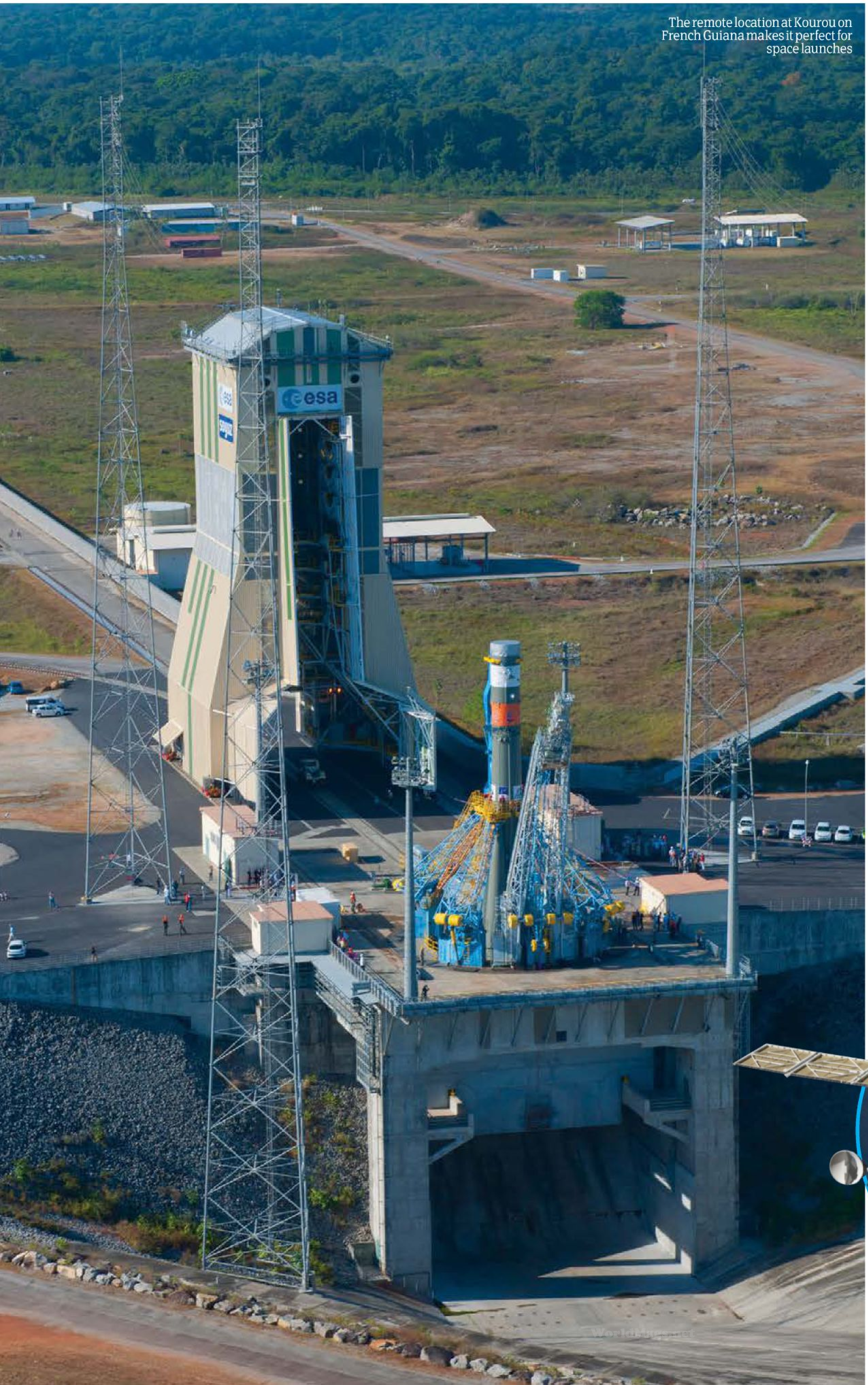
A look around the ESA's history-making launch pad

The sight of a rocket igniting and blasting off is one of the most awe-inspiring things anyone can ever watch. For the lucky people in Kourou, French Guiana, this is a regular occurrence, thanks to the European Space Agency's (ESA) multi-rocket launch pad. With the birth of the ESA, the French-built launch pad was selected as the place from where all European-funded missions take off.

The Ensemble de Lancement Soyouz (ELS) is made up of three specific sections. There is the preparation area, where rockets are put together, the launch control centre, a safe bunker, which houses the scientists and engineers involved in the launch, and finally the launch platform, the 53-metre (174-foot) high tower that holds the rocket steady and vertical until the moment it takes off. The site is fairly spread out, with the control centre one kilometre (0.6 miles) away from the launch pad, which is connected to the preparation area by a 700-metre (2,300-foot) long railway.

In 2011, history was made at ELS as a Soyuz rocket, the most famous Russian-made rocket, was launched from the site. It was a momentous occasion as it was the first of the flagship Russian rockets ever to be launched outside of Kazakhstan or Russia.

Looking to the future, plans are being made for Skylon, a British spaceplane, to launch from the site. The exciting thing about Skylon is that parts are reusable and can be turned around in hours, making huge savings. Although the runway at Kourou would need strengthening, the ESA has already shown active willingness to pump money into the site, having already spent €1.6 billion (£1.3 billion/$2.2 billion) on improving and upgrading the site. There is also the option to store liquid hydrogen at the site, as there are plans to use it as a fuel for future Soyuz rockets.



The remote location at Kourou on French Guiana makes it perfect for space launches

What makes Kourou perfect?

Kourou is an ideal site for a range of launches. French Guiana is one of the northernmost countries in South America. It sits at latitude 5°3', which means it's only 500km (311mi) north of the equator, ideal for geostationary orbit launches as the rocket won't need to make many adjustments to get the satellites into their planned orbit.

Other pros to being near the equator include the slingshot effect. As the equator is the widest point of the Earth, it has the largest distance of rotation of any part of the planet. Spacecraft can use this rotation to vastly increase the speed of the rocket and save fuel on launch.

French Guiana is ideal because 90 per cent of the land is covered in uninhabitable forests so the population is low. This means disruption to the locals is minimal.

Ready for Soyuz

A huge coup in the history of ELS was in 2003 when the Russian and French governments came to an agreement to begin launching Soyuz rockets from Kourou.

Updates were required to make it suitable for the Soyuz rockets to launch there. One of the key changes was the construction of a moveable tower, which could be placed next to the launch pad, providing access for engineers up to a height of 36m (118ft). However, the tower itself rose 53m (174ft) high and was the cause of delays to the programme.

The first rockets scheduled for launch arrived in November 2009 and in October 2011 the first Soyuz rocket ever to be launched outside of Kazakhstan and Russia took off on its maiden voyage.

© ESA

How does the Mars Hopper hop?

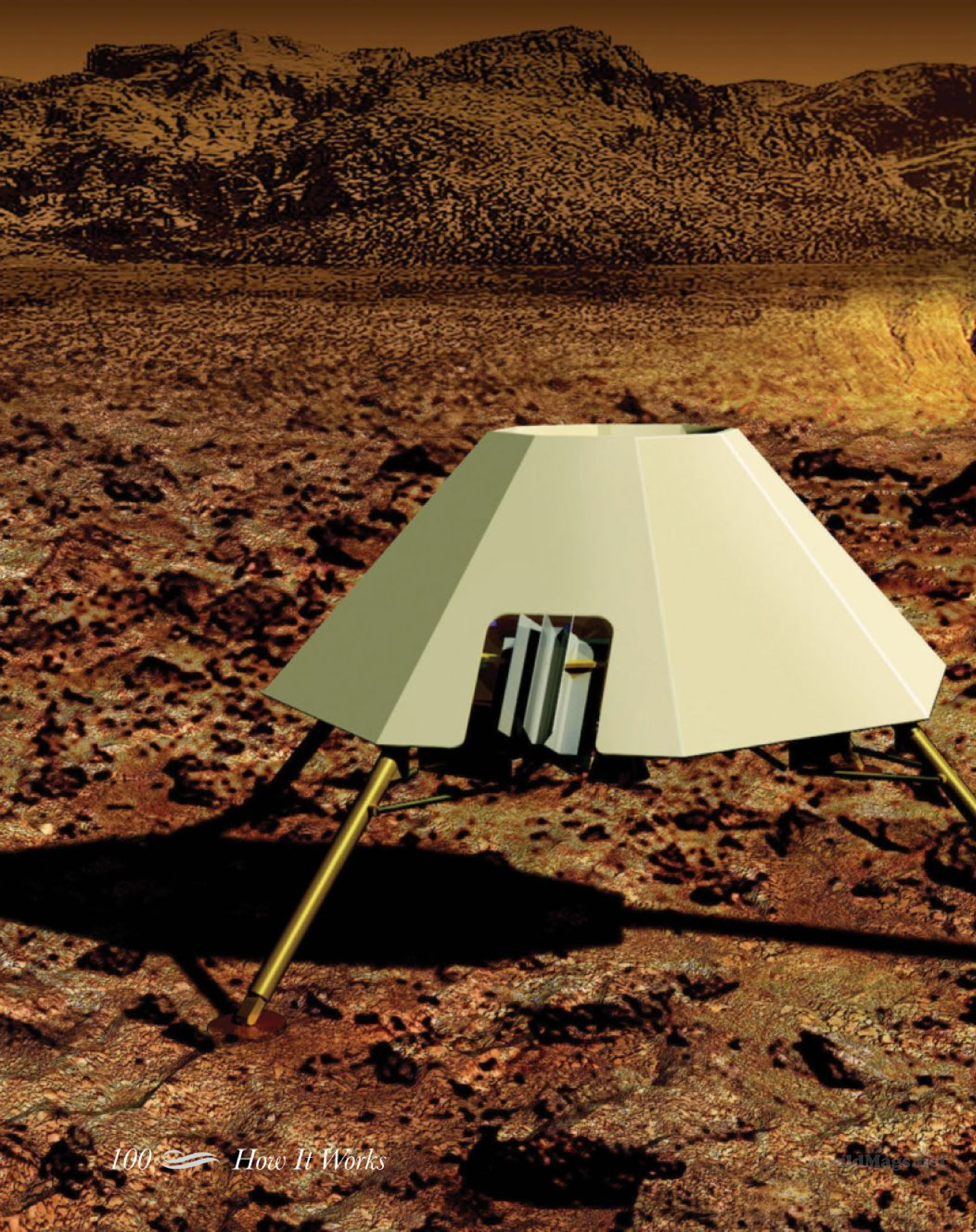
The Martian vehicle that will hop, skip and jump its way around the Red Planet

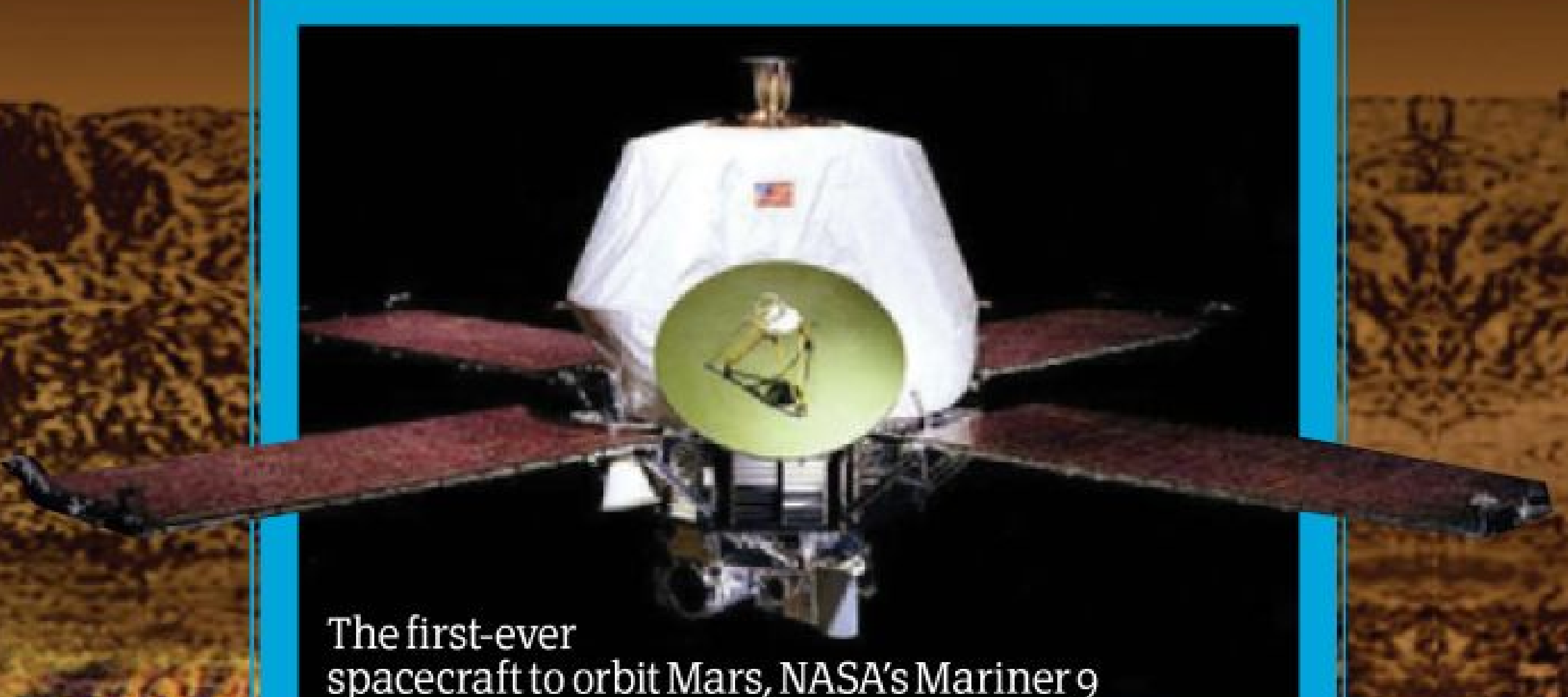
British scientists have designed a robot that could roam the Red Planet by jumping over 0.8 kilometres (half a mile) at a time. The Mars Hopper will tackle the rocky landscape by leaping over obstacles.

The Hopper measures 2.5 metres across and weighs 1,000 kilograms, which is slightly more than NASA's Curiosity rover. One hop could launch the vehicle up to 900 metres at a time. To achieve this, a radioactive thermal capacitor core will provide thrust through a rocket nozzle. The Martian atmosphere, thick in carbon dioxide, would provide the fuel as it is compressed and liquefied within the Hopper.

If successful, the Hopper would allow rapid exploration of Mars with tricky terrains like hills, craters and canyons much easier to navigate. On current vehicles such as the Exploration rovers, the wheels have become stuck on slopes and the sandy, rocky texture of the planet's surface. The Hopper will use magnets in its four-metre leg span to allow it to leap again and again. The magnets will create an eddy current to produce a damping effect.

Proposed by experts from the company Astrium and the University of Leicester, the concept was first designed in 2010. A slight issue lies in the rate of CO2 gathering, with the current system taking several weeks to completely fill the fuel tank. However, the vehicle will more often than not be at a standstill as it thoroughly scours the Martian landscape, so this should not pose an immediate problem.





The first-ever spacecraft to orbit Mars, NASA's Mariner 9

Martian exploration programmes

The first craft to attempt to explore Mars was launched way back in 1960 when the USSR's 1M spacecraft failed to leave Earth's atmosphere. After various unsuccessful launches by the USA and the Soviet Union, NASA's Mariner 9 became the first craft to orbit the planet in 1971. In 1975 the Viking 1 lander was the first to successfully touch down on the surface. The USSR managed to orbit Mars only weeks after the Mariner with their Mars 2 spacecraft but have not yet landed on the planet. The most recent lander is NASA's Curiosity, which was launched in 2011 and is tracking the Martian surface as we speak. The third organisation to get in on the act was the ESA (European Space Agency) who launched the Mars Express and Beagle 2 Lander in 2003. The Express has successfully orbited the planet but unfortunately communication was lost with Beagle 2 after its deployment. The most recent NASA craft is MAVEN, the Mars Atmospheric and Volatile EvolutioN, which launched in 2013 and will enter Martian orbit this September.

Also in 2013, the Indian Space Research Organization (ISRO) launched its Mars Orbiter Mission (MOM) in its bid to become the fourth space agency to reach the red planet.

© NASA; ESA, Airbus Defence and Space in Stevenage in cooperation with the University of Leicester

Why launch a satellite in mid-air?

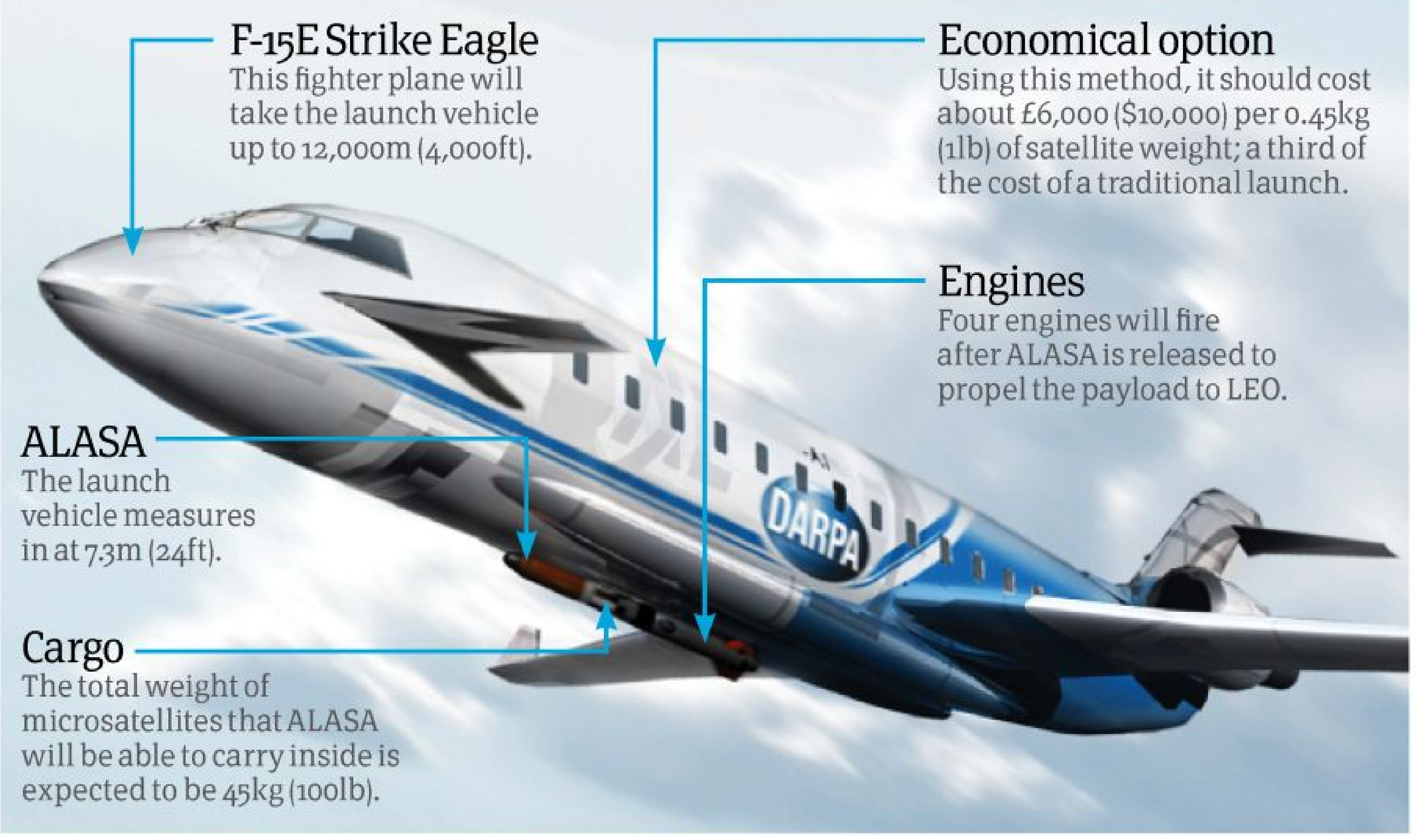
Why sending off satellites from a plane offers many benefits over land-based launch pads

Planning is well underway on a launch vehicle that will slash the cost of launching a satellite by doing it from the air rather than the ground.

Boeing and the Defense Advanced Research Projects Agency (DARPA) have joined forces to create a machine that will strap onto the underside of a modified F-15E aircraft. Upon reaching 12,000 metres (40,000 feet) the Airborne Launch Assist Space Access (ALASA) will get jettisoned and then use its own four engines to enter a low-Earth orbit (LEO), where it will release its payload of microsatellites.

The benefit of this construction is that it should save 66 per cent on each satellite launch by not having to use and discard a fuel tank and engine. Another big benefit is that the satellites can be sent up from standard runways all over the world, rather than a few limited launch pads, truly democratising space exploration.

As of 2015 Boeing has built 12 ALASA vehicles and the project is still ongoing.



F-15E Strike Eagle
This fighter plane will take the launch vehicle up to 12,000m (4,000ft).

Economical option
Using this method, it should cost about £6,000 ($10,000) per 0.45kg (1lb) of satellite weight; a third of the cost of a traditional launch.

Engines
Four engines will fire after ALASA is released to propel the payload to LEO.

ALASA
The launch vehicle measures in at 7.3m (24ft).

Cargo
The total weight of microsatellites that ALASA will be able to carry inside is expected to be 45kg (100lb).

A computer-generated view of Sapas Mons, a large volcano on the planet Venus

Why are there so many volcanoes on Venus?

Venus has more volcanoes than any other planet in the Solar System

It's incredibly hot, with a searing average temperature of 460 degrees Celsius (860 degrees Fahrenheit) - much muggier than deserts on Earth. Its atmosphere is thick with choking carbon dioxide, laced with poisonous sulphuric acid clouds that hang above a parched landscape. This is the setting of the second planet from the Sun, Venus – also known as Earth's evil twin – and it's taken some of our comparatively tranquil planet's characteristics to the absolute extreme.

In a world where you would be cooked, crushed and choked within a few seconds, Venus has its dominating network of volcanoes to thank for its hellish state – over 1,600 volcanoes that have been so active in Venus' past have unpredictably erupted to renew the planet's surface with plains of lava. From high peaks to volcanoes built almost entirely from fluid lava flows and the unusual volcanic pancake domes, Venus is a geological paradise. How did they get here in the first place and why are there so many?

Venus' anger under the planet's crust made the volcanoes so many probes have detected through its thick cloud layer. Magma works its way to the surface, making some of these volcanoes bigger and bigger. Why the planet has so many is all down to the lack of the wind and water erosion witnessed on Earth – without these, they're never destroyed.

Volcano in Eistla Regio on Venus, from the Magellan radar-mapping spacecraft

© Science Photo Library; NASA

Venus' king of volcanoes

Out of the many volcanoes found on Venus' hellish surface, Maat Mons in the highest of them all, reaching a tall eight kilometres (five miles) toward the thick Venusian skies. Whether Venus is still volcanically active is still something that cannot be decided among the scientific community, as present-day eruptions of this monstrous peak are yet to be confirmed.

What is the greatest risk to Earth?

Hurtling above us are thousands of pieces of space junk

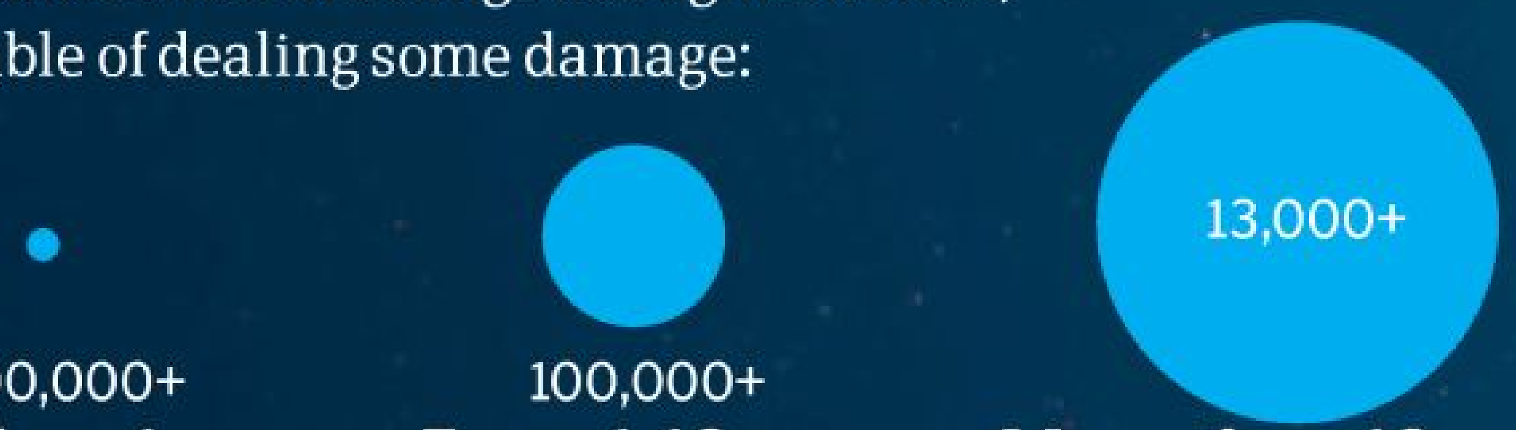
Since the launch of the first satellite, Sputnik 1, in 1957, the area of space near the Earth has been populated with countless pieces of debris. Fragments from satellites that have been damaged or destroyed, and parts of rockets and spacecraft remain in orbit, forming a true cosmic dump. The danger of these objects is due to the risk of collision: they can travel at speeds of up to 70,000 kilometres (43,496 miles) per hour. Even tiny chunks of debris can have a devastating effect on anything in their path when travelling at such speeds, as depicted in the 2013 critically acclaimed blockbuster Gravity. ✱

Space debris

Any artificial object without use that's orbiting around the Earth is considered space debris. Single-use rockets can remain in orbit, just like spaceship parts or machines removed unintentionally to prevent them from entering the wrong orbit. There is a wide range of objects; for instance, in 1965, Edward White lost a glove that kept orbiting at 28,000 kilometres (17,398 miles) per hour for a month!

Space debris size

Space junk comes in a range of fragment sizes, all capable of dealing some damage:



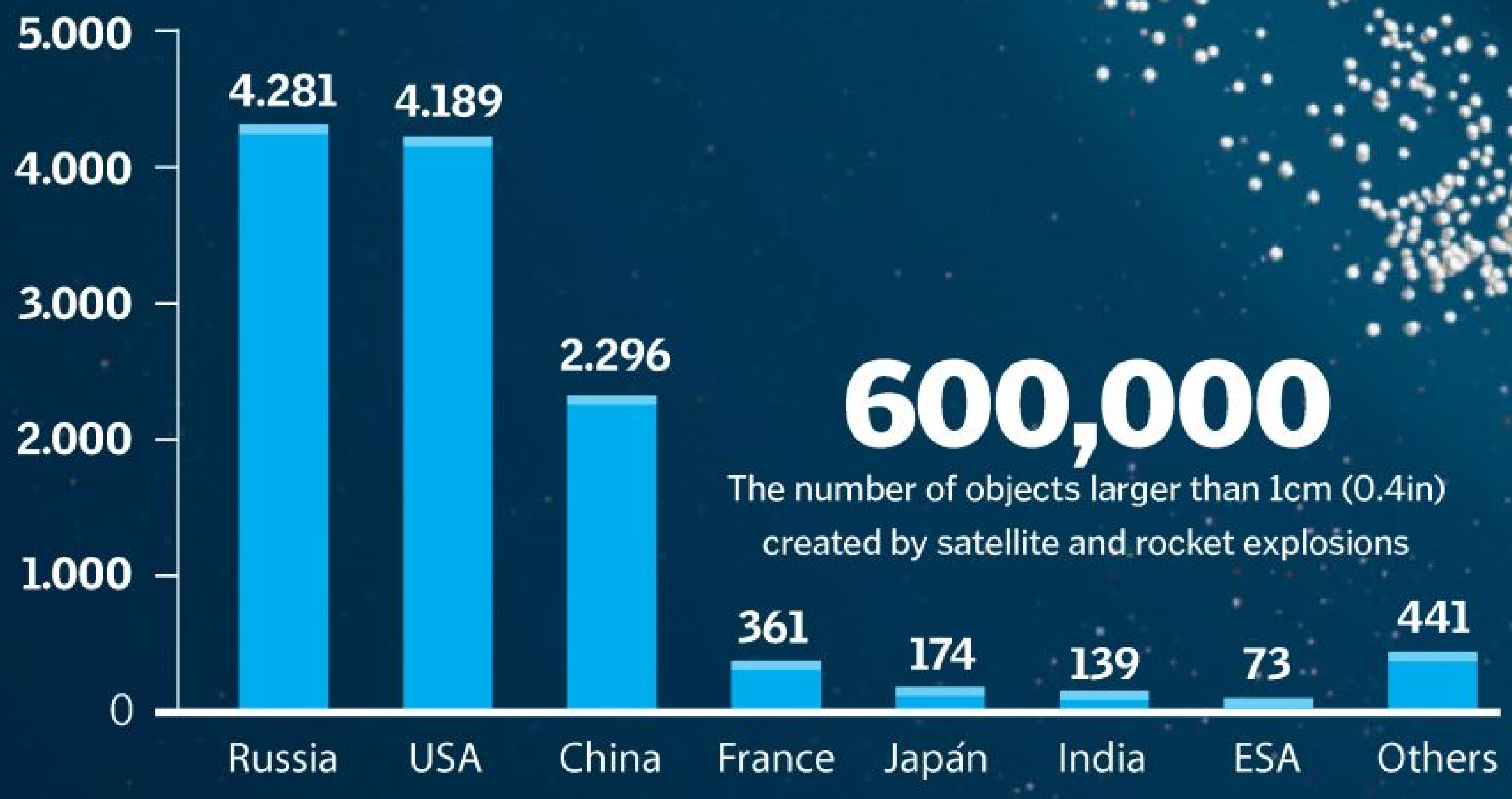
30,000,000+
Less than 1cm
Very small particles that cause small surface damage.

100,000+
From 1-10cm
These particles can make holes in satellites.

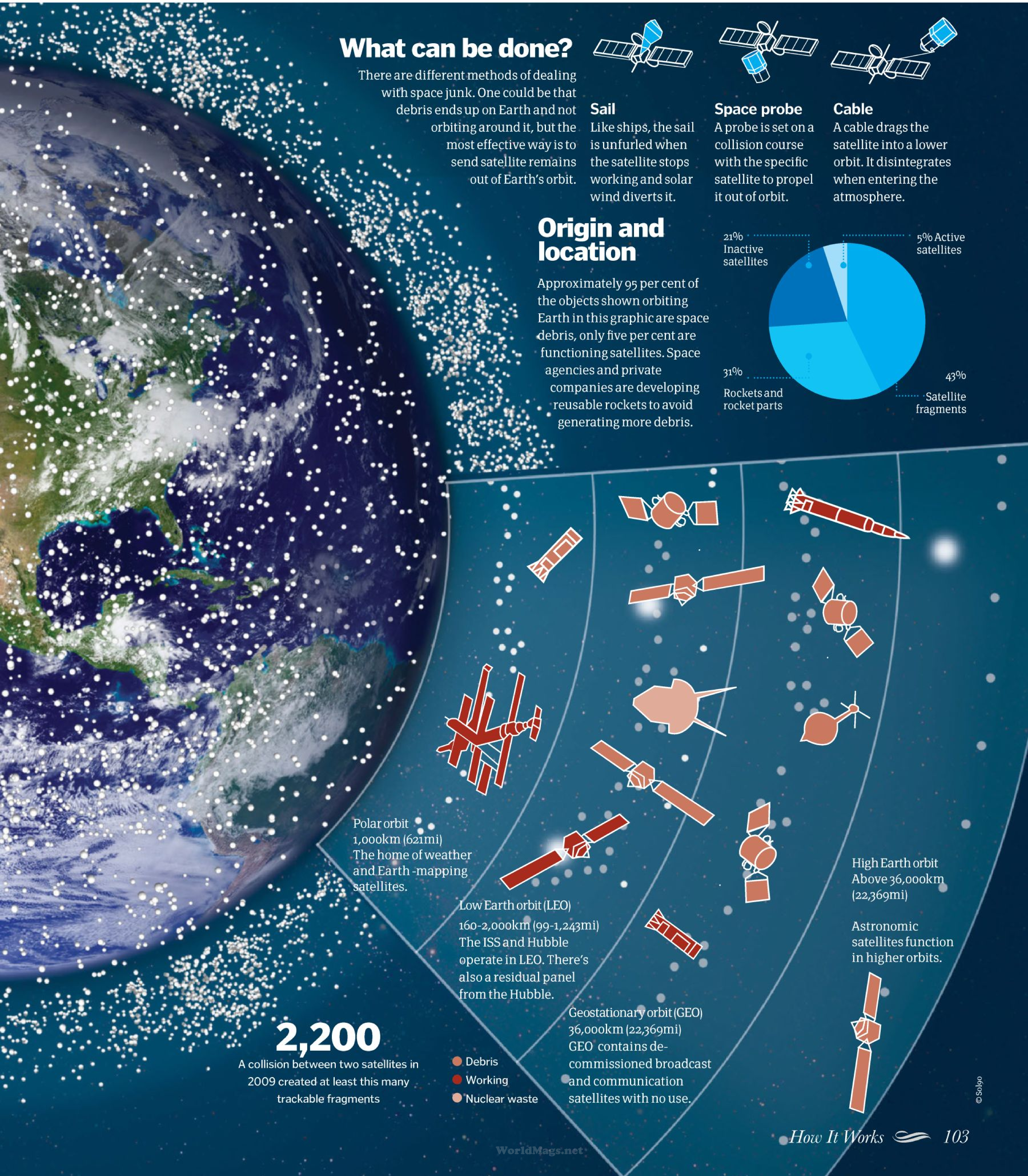
More than 10cm
These can cause damage beyond repair. These are the objects that are classified.

Classified objects in space by countries

There are over 25,000 objects that have been launched to the low Earth orbit since 1957. The United States and Russia have launched the most.



600,000
The number of objects larger than 1cm (0.4in) created by satellite and rocket explosions



What can be done?

There are different methods of dealing with space junk. One could be that debris ends up on Earth and not orbiting around it, but the most effective way is to send satellite remains out of Earth's orbit.

Sail
Like ships, the sail is unfurled when the satellite stops working and solar wind diverts it.

Space probe
A probe is set on a collision course with the specific satellite to propel it out of orbit.

Cable
A cable drags the satellite into a lower orbit. It disintegrates when entering the atmosphere.

Origin and location

Approximately 95 per cent of the objects shown orbiting Earth in this graphic are space debris, only five per cent are functioning satellites. Space agencies and private companies are developing reusable rockets to avoid generating more debris.

Polar orbit
1,000km (621mi)
The home of weather and Earth -mapping satellites.

Low Earth orbit (LEO)
160-2,000km (99-1,243mi)
The ISS and Hubble operate in LEO. There's also a residual panel from the Hubble.

Geostationary orbit (GEO)
36,000km (22,369mi)
GEO contains de-commissioned broadcast and communication satellites with no use.

High Earth orbit
Above 36,000km (22,369mi)

Astronomic satellites function in higher orbits.

2,200
A collision between two satellites in 2009 created at least this many trackable fragments

● Debris
● Working
● Nuclear waste

© Sol90

How do you power a spacecraft?

The incredible sci-fi technology made a reality

Ion propulsion studies began in the 1950s, with NASA's Glenn Research Center engineering the earliest ion thrusters for rocket propulsion.

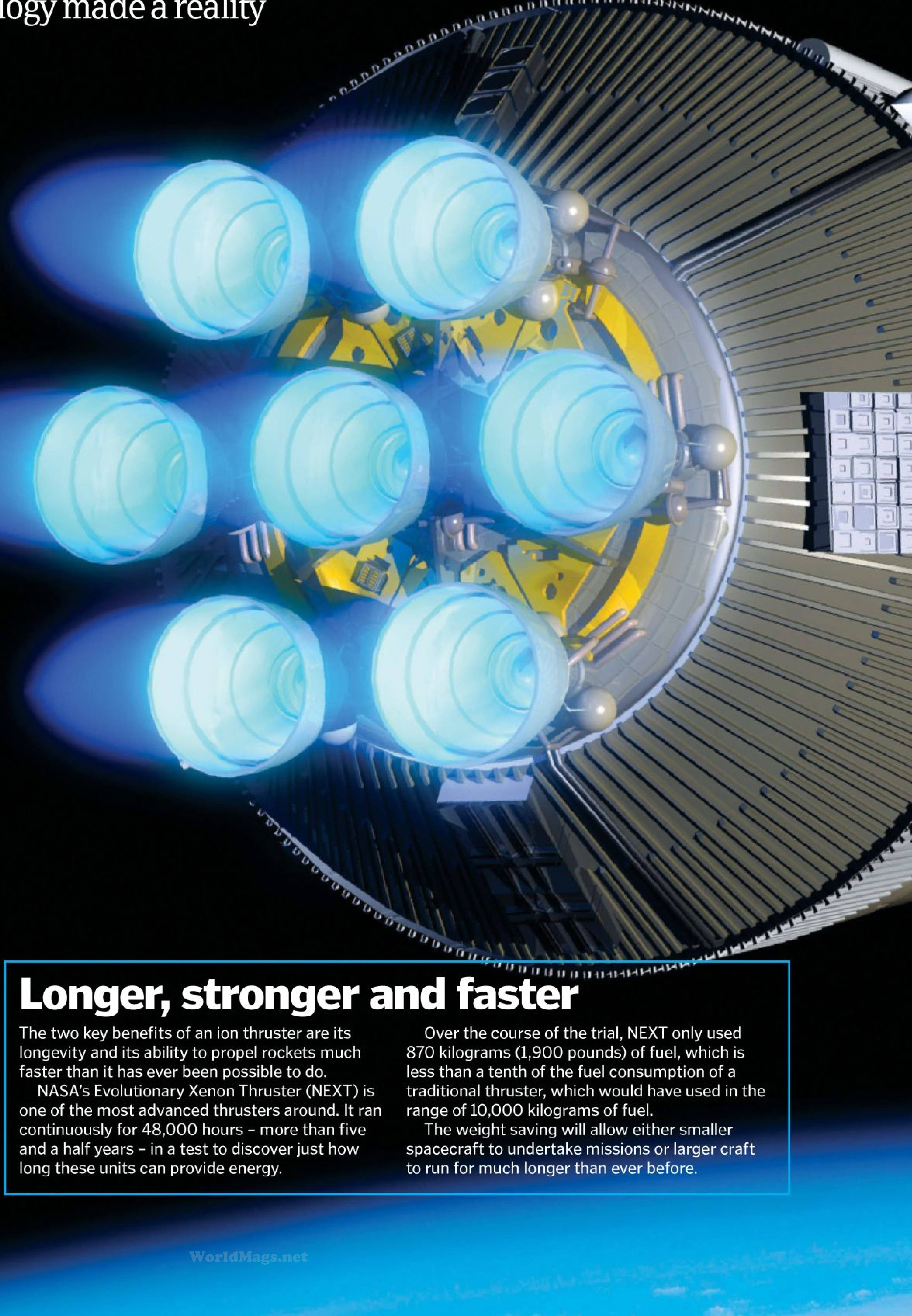
In the system, electrons get pushed into the thruster via a cathode tube. These electrons, which have an innate negative charge, come into contact with the propellant – typically the noble gas xenon – in the discharge chamber, drawn by strong electromagnets. When afree electron hits a neutral atom from the propellant, the xenon breaks into twonegative electrons and a positive ion.

The ions then get forced into ion optics, which are electrodes that contain thousands of coaxial apertures. The end that is closer to the exit is negatively charged and the end closer to the rocket is positively charged. The positive ions stream toward the negatively charged end of the apertures, get compressed and forman ion stream. This ion stream then shootsout of the end of the thruster, providingthe force to propel the rocket.

In order to keep the overall system neither positive nor negative, a cathode tube called a neutraliser pumps a stream of negatively charged electrons into the ion stream once it has been expelled to mix with the positively charged ions and balance out the whole process so the exhaust remains neutral.

The main benefit of ion thrusters is that they are able to propel rockets at a much faster pace than a chemically powered rocket. The now-retired Space Shuttle could travel at a top speed of 28,000 kilometres (17,400 miles) per hour, but an ion thruster allows for a speed of 322,000 kilometres (200,000 miles) per hour!

The downside is that, unfortunately, the amount of thrust generated by ion propulsion is minuscule. An ion thruster can only create as much as 0.5 Newtons (0.1 pounds) of force, which is about as much as holding ten small coins (20 pence or quarter dollar) in your hand. Therefore, acceleration is extremely slow but it can continue over a very long period of time. ✽



Longer, stronger and faster

The two key benefits of an ion thruster are its longevity and its ability to propel rockets much faster than it has ever been possible to do.

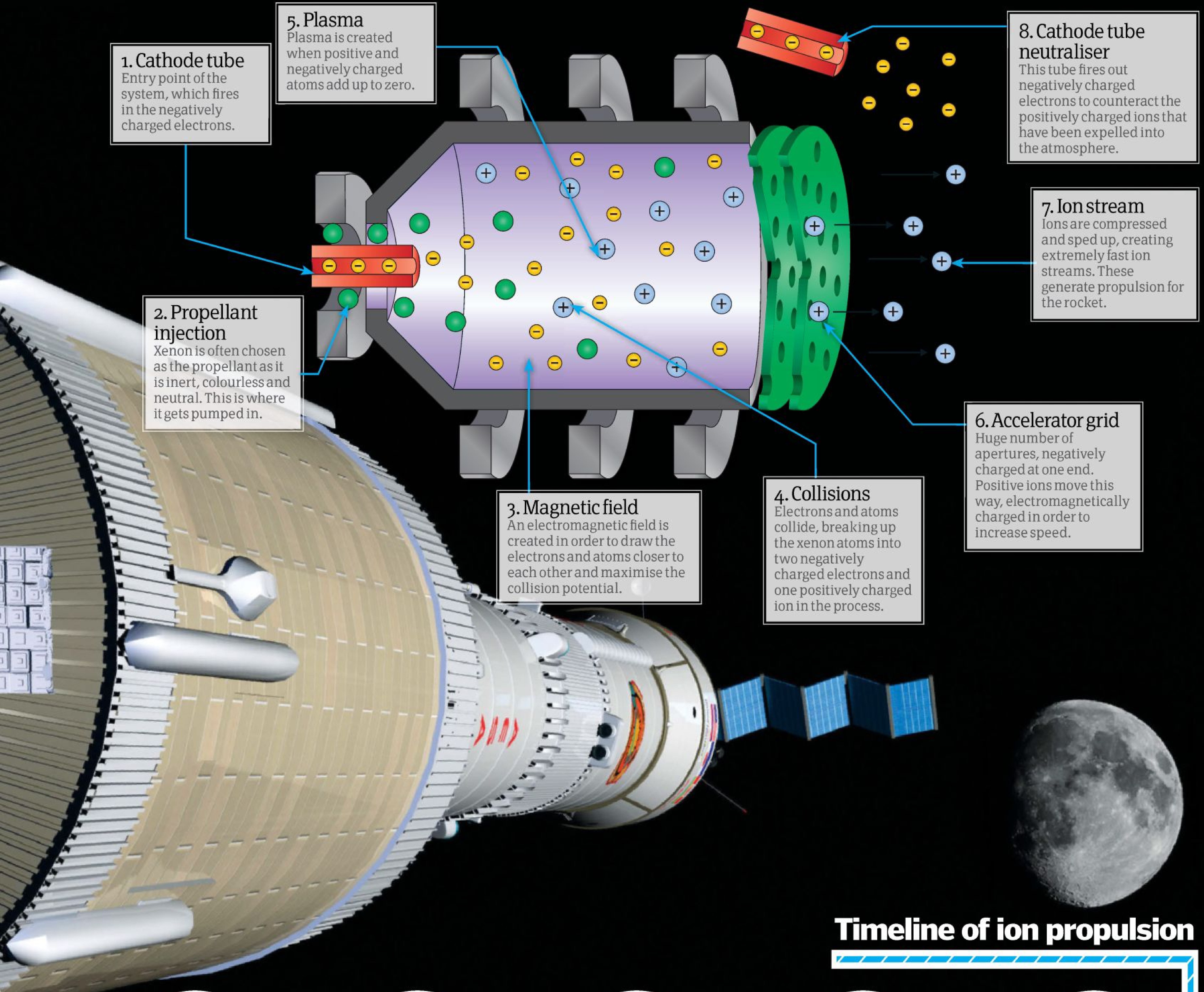
NASA's Evolutionary Xenon Thruster (NEXT) is one of the most advanced thrusters around. It ran continuously for 48,000 hours – more than five and a half years – in a test to discover just how long these units can provide energy.

Over the course of the trial, NEXT only used 870 kilograms (1,900 pounds) of fuel, which is less than a tenth of the fuel consumption of a traditional thruster, which would have used in the range of 10,000 kilograms of fuel.

The weight saving will allow either smaller spacecraft to undertake missions or larger craft to run for much longer than ever before.

Ion thruster science

The inner workings of the machines powering deep-space exploration



1. Cathode tube
Entry point of the system, which fires in the negatively charged electrons.

2. Propellant injection
Xenon is often chosen as the propellant as it is inert, colourless and neutral. This is where it gets pumped in.

3. Magnetic field
An electromagnetic field is created in order to draw the electrons and atoms closer to each other and maximise the collision potential.

4. Collisions
Electrons and atoms collide, breaking up the xenon atoms into two negatively charged electrons and one positively charged ion in the process.

5. Plasma
Plasma is created when positive and negatively charged atoms add up to zero.

6. Accelerator grid
Huge number of apertures, negatively charged at one end. Positive ions move this way, electromagnetically charged in order to increase speed.

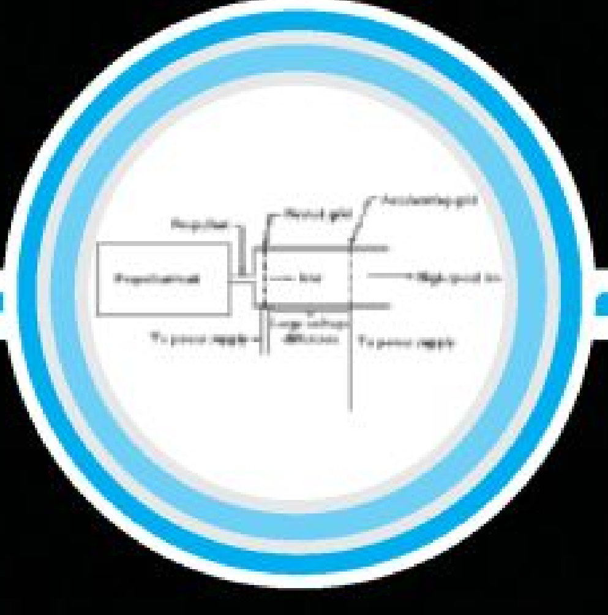
7. Ion stream
Ions are compressed and sped up, creating extremely fast ion streams. These generate propulsion for the rocket.

8. Cathode tube neutraliser
This tube fires out negatively charged electrons to counteract the positively charged ions that have been expelled into the atmosphere.

Timeline of ion propulsion

1932
German inventor Dr Wernher von Braun is given a grant to look into the possibility of running electric-propulsion rocket engines.

1946
Dr Ernst Stuhlinger observes a V-2 rocket travel 190km (120mi) and, after the war, helps Von Braun build a long-range rocket for the US Army.



1959
One of the first ion engines to be created is at NASA. It is powered by caesium and based on designs drawn up by Stuhlinger.

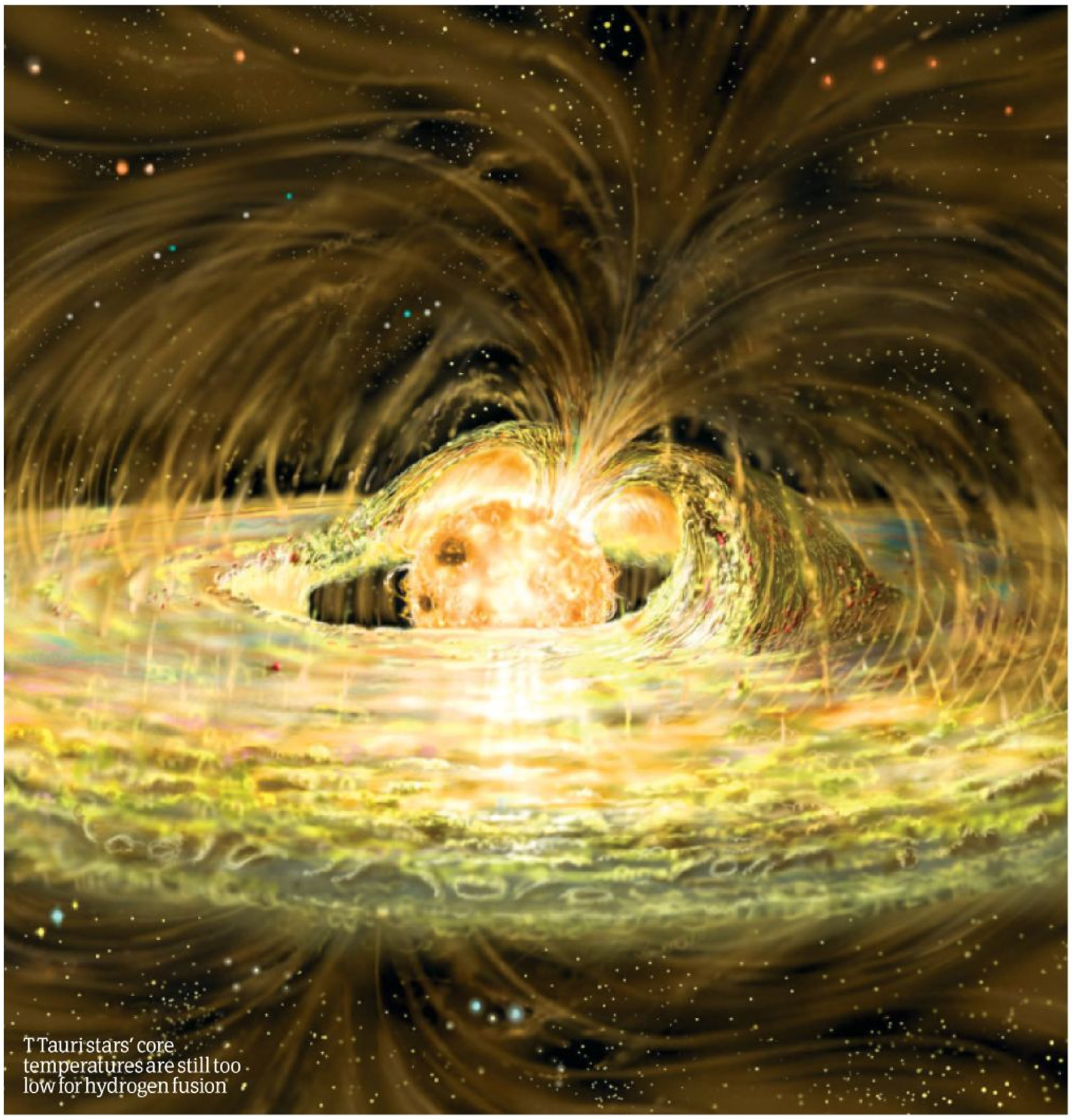
1992
The Jet Propulsion Laboratory and NASA collaborate to develop a xenon-powered ion engine – the model for the modern-day ion thruster.

1998
Ion thrusters are the main source of power on Deep Space 1, a three-year mission that involves a rendezvous with Comet Borrelly.

© Alamy; NASA

What is an infant star?

Get to know the youngsters of the night sky and what they can teach us



T Tauri stars' core temperatures are still too low for hydrogen fusion

A 'T Tauri' is a type of star that is still very much in its infancy. Usually less than 10 million years old, these stars are undergoing constant gravitational contraction. Over a few million years, this contraction will create enough heat and pressure at the core to ignite hydrogen fusion and turn the T Tauri into a main-sequence star.

One of the most fascinating things about T Tauri stars is the stellar winds and jets that develop around them. These are thought to occur when material floats into the accretionary disc that forms around the star and reacts with it, sending off shoots of gas.

As well as being visually interesting, T Tauri stars – named after the first one discovered – provide a snapshot into our own history. Our own Sun and Solar System went through this process around 5 billion years ago, so studying T Tauri stars should provide us with some great insight into our own origins. ✱

What makes a planet red?

Mars isn't alone in the Solar System…

Back in 2003, a planetoid beyond the Kuiper Belt was discovered. Red in colour, it was named Sedna, after the Inuit goddess of the ocean.

Astronomers at Caltech spotted the 1,800-kilometre (1,120-mile) wide body, which is slightly smaller than Pluto, using the Samuel Oschin Telescope. Its size means that Sedna's exact classification is still under debate. Sedna has an elliptical orbit that can take it as far as 140 billion kilometres (87 billion miles) away from the Sun, with an average distance of 5.9 billion kilometres (3.7 billion miles), taking 11,400 years to perform a single orbit.

Sedna's redness is thought to be caused by either tholin, organic aerosols made by fusing methane and nitrogen, or hydrocarbons. Surface temperatures can get as low as -240 degrees Celsius (-400 degrees Fahrenheit). ✱

Sedna is one of the most distant known objects in the Solar System

© NASA; SPL

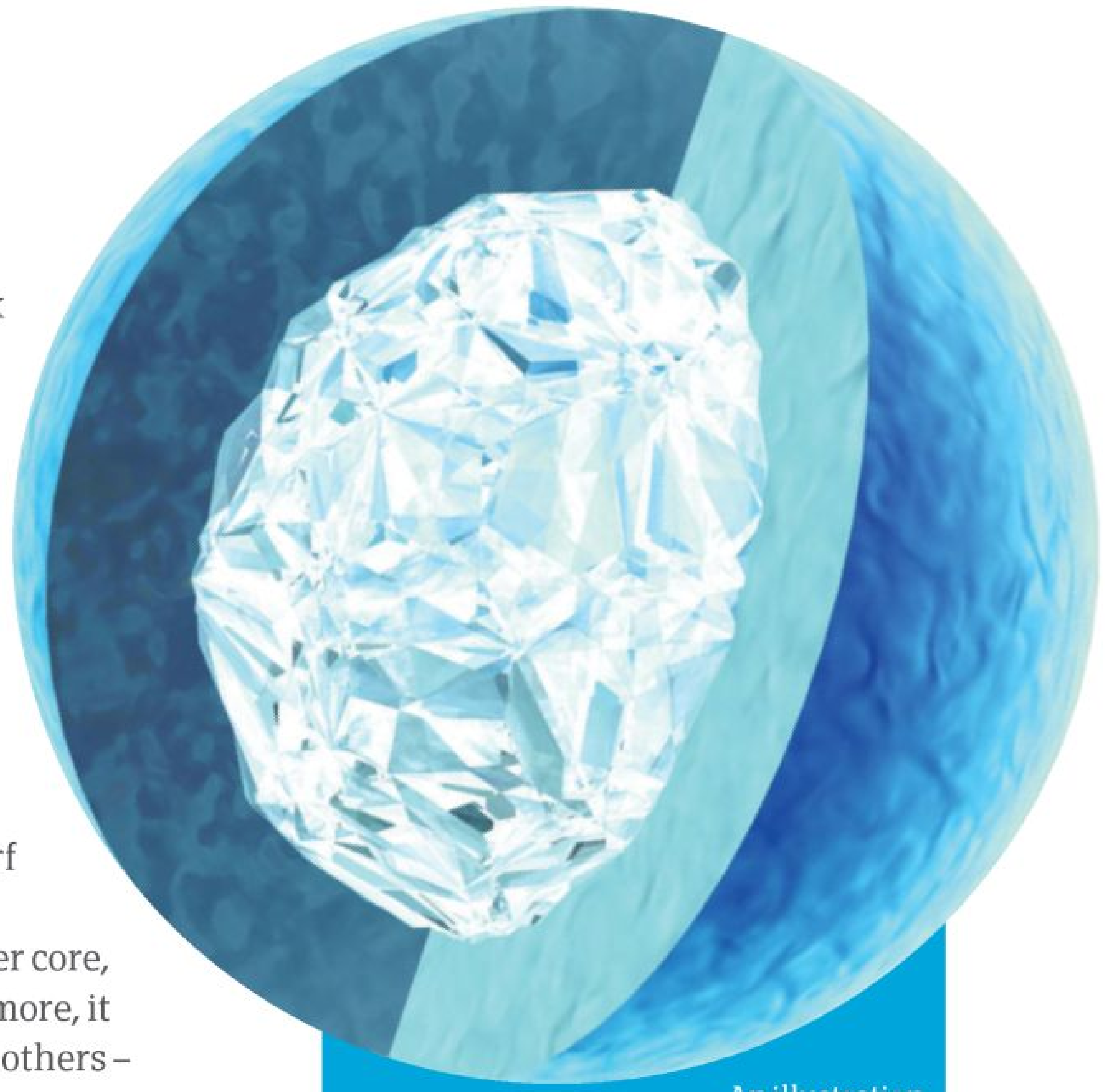
Can a planet have a diamond core?

Some alien worlds are a girl's best friend, for just beneath their surface is a core of solid diamond

Earth is an oxygen-rich planet; it's in the air that we breathe, the water that we drink and the silicate rock that we stand on. Imagine a planet, though, where there is hardly any oxygen but lots of carbon instead. These 'carbon planets' hold a special secret – below the surface the high pressures crush the carbon into graphite (the 'lead' in your pencil) and, even deeper, into diamond.

Astronomers have shown that planets form by condensing from disks of dust and gas around young stars. If the ratio of carbon to oxygen in these disks is higher than 0.65 then carbon-rich rocky worlds can be assembled. Life on such worlds would be difficult, if impossible, because there is so little oxygen that it's unlikely there would be much water. The atmosphere would be thick with carbon dioxide and poisonous carbon monoxide, into which towering mountains of graphite form, while below the bedrock would be as hard as diamond because that's literally what it would be.

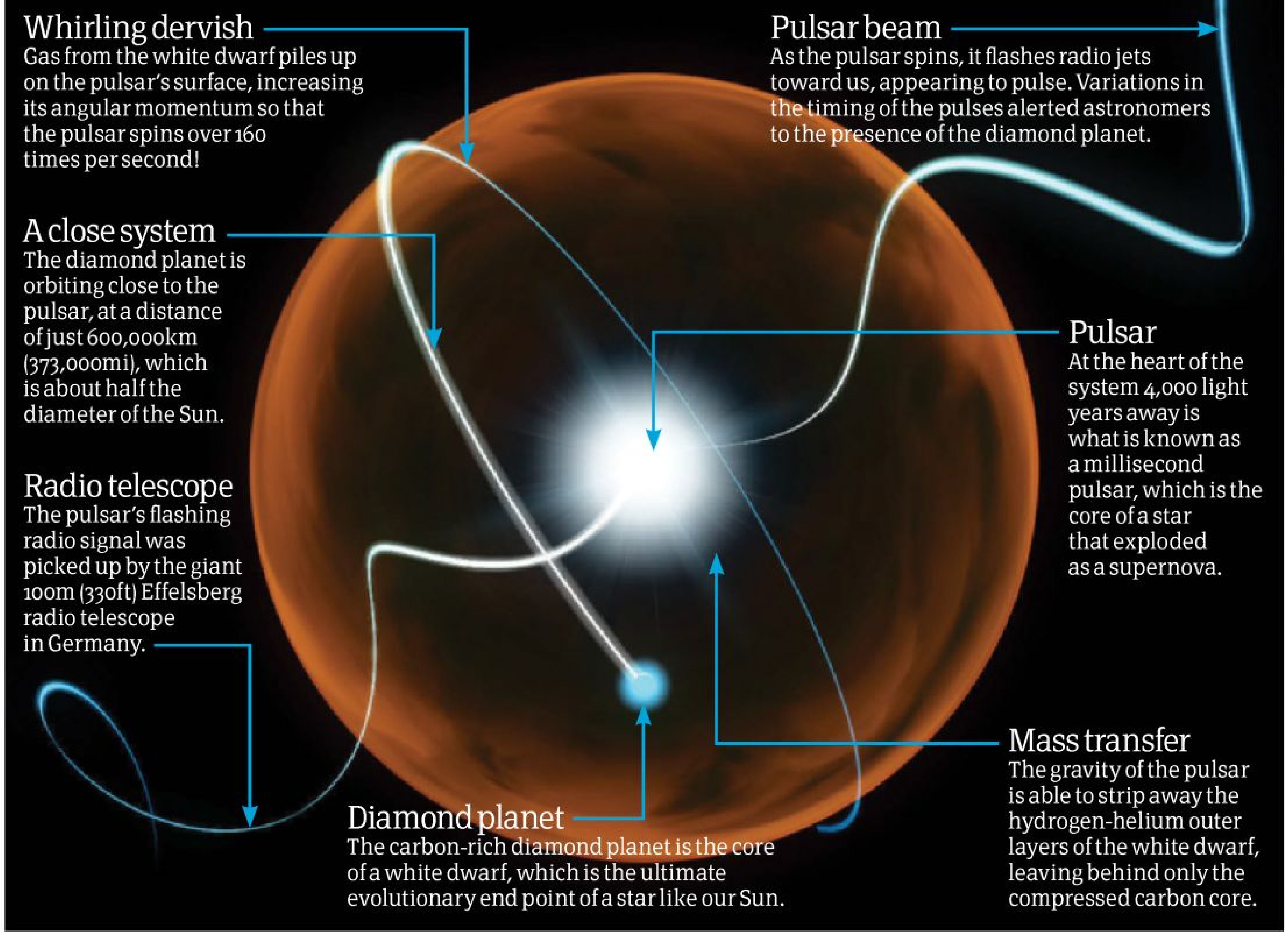
Not all diamond planets are made in the same fashion. One suspected carbon 'planet' found orbiting a pulsar – a spinning supernova remnant emitting beams of radio waves – is believed to have once been a star itself. The star grew old and died, leaving behind a white dwarf, which is about the size of Earth. This white dwarf lost its outer layers to the gravity of the pulsar, revealing the white dwarf's inner core, made of solid crystal diamond. What's more, it will outlast our Solar System and many others – this diamond really is forever!



An illustration of what the inside of a diamond planet may look like

The star that became a carbon planet

How could a burning star turn into an astronomical clump of diamond?



Whirling dervish
Gas from the white dwarf piles up on the pulsar's surface, increasing its angular momentum so that the pulsar spins over 160 times per second!

Pulsar beam
As the pulsar spins, it flashes radio jets toward us, appearing to pulse. Variations in the timing of the pulses alerted astronomers to the presence of the diamond planet.

A close system
The diamond planet is orbiting close to the pulsar, at a distance of just 600,000km (373,000mi), which is about half the diameter of the Sun.

Pulsar
At the heart of the system 4,000 light years away is what is known as a millisecond pulsar, which is the core of a star that exploded as a supernova.

Radio telescope
The pulsar's flashing radio signal was picked up by the giant 100m (330ft) Effelsberg radio telescope in Germany.

Mass transfer
The gravity of the pulsar is able to strip away the hydrogen-helium outer layers of the white dwarf, leaving behind only the compressed carbon core.

Diamond planet
The carbon-rich diamond planet is the core of a white dwarf, which is the ultimate evolutionary end point of a star like our Sun.

The mysterious case of 55 Cancri e

Discovered in 2004, the exoplanet 55 Cancri e is the closest of five worlds found to orbit the star 55 Cancri in the constellation of Cancer. It is a super-Earth with twice the diameter of our planet and over eight times the mass. Because it is seen to transit in front of its star, astronomers are able to make accurate measurements of the planet's chemical make-up. They detected no hydrogen, which is odd. Hydrogen is the most common element in the universe, but it is also the lightest, and that close to its star it will be blown away unless it is locked into a molecule such as water. Water, however, needs oxygen, but a carbon planet would have no oxygen and hence no water or hydrogen. However, it was subsequently discovered that its star has 25 percent more oxygen than carbon, implying the planets should follow suit. If that is the case, then 55 Cancri e cannot be a carbon world, leaving its exact nature still a mystery at this point.

© Adrian Mann

What are magnetic stars made from?

Meet a star with a magnetic field that's quadrillions of times more powerful than Earth's

There are plenty of exotic objects in the universe and many might agree that the magnetar fits neatly into this category. Magnetars are exactly what their name infers – they are stars with a monstrous magnetic field, quadrillions of times stronger than any magnet humans can build. It's said the magnetar is so powerful that if you placed one at a distance halfway to the Moon, it would have no trouble stripping information from all the credit cards in the world. But what makes them so powerful?

Magnetars are rapidly spinning neutron stars, made from the collapse of a massive star during a supernova explosion. However, the full details of how they are made is still a mystery that continues to baffle astronomers to this day. It's said that if you were to scoop a teaspoon full of material from this object's surface, it would weigh in at 1 billion tons. What's more, a magnetar can also shift its bulk at alarming speeds, completing one pirouette in no more than ten seconds. It's also capable of spitting out very strong bursts of X-rays and gamma rays – the most penetrative of radiation – which is truly characteristic of the magnetar.

These bizarre objects don't live for very long in astronomical terms. It's believed they start to feel their age and wind down after about 10,000 years and, as a result, astronomers estimate there are at least 30 million inactive magnetars in the Milky Way galaxy compared to a very much alive and confirmed 23. ✻

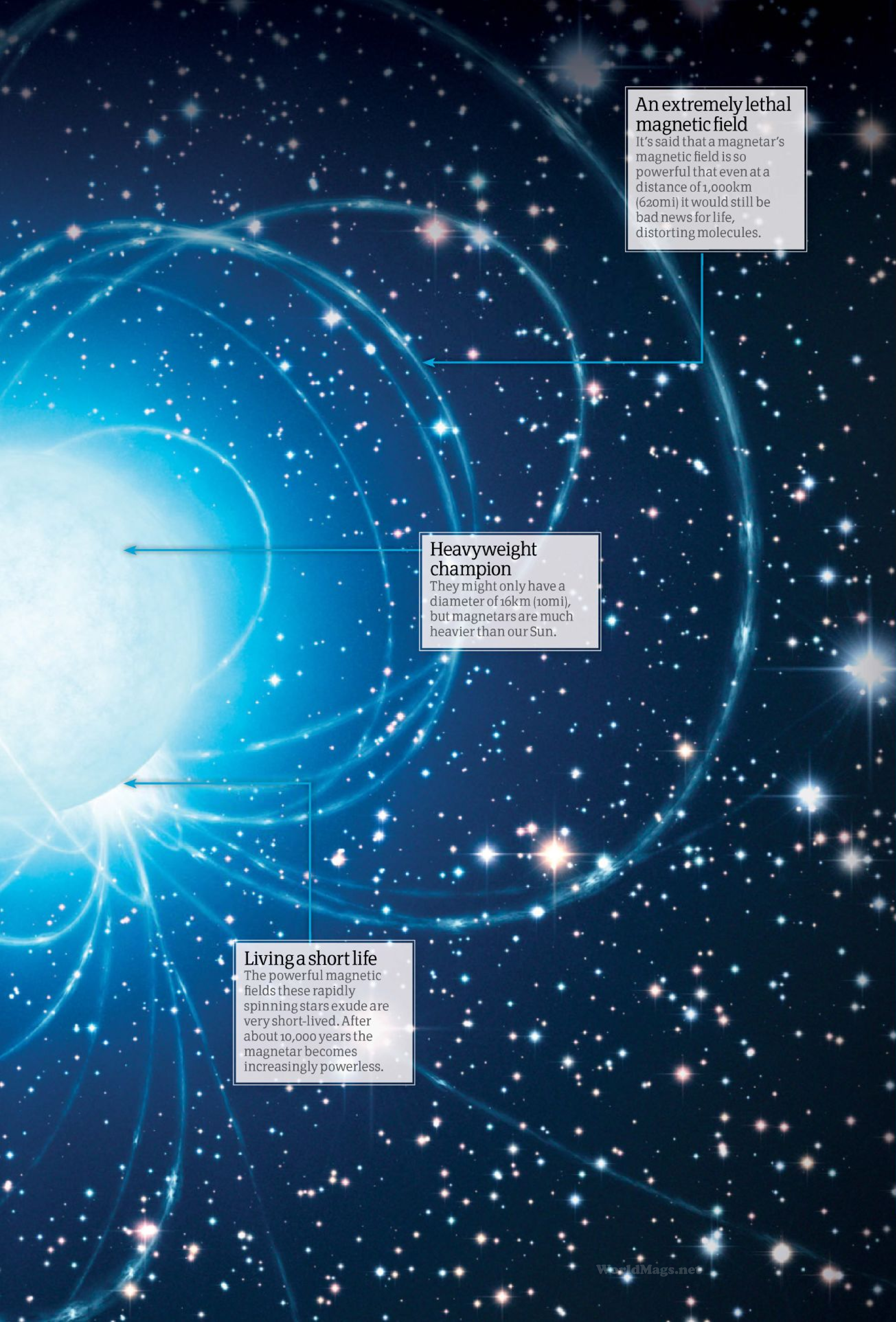
Dynamo power!
It's thought an extremely turbulent, yet dense, fluid provides the magnetar with its incredibly powerful magnetic field.

An explosive formation
Magnetars are made when, in a supernova, a star collapses to make a neutron star with its magnetic field increasing dramatically in strength.

A dying breed
To date, just over 20 active magnetars have been found. Estimates suggest there are likely to be over 30 million 'dead' magnetars in the Milky Way alone.

Anatomy of the magnetar

The astronomical make-up the universe's strongest magnets



An extremely lethal magnetic field
It's said that a magnetar's magnetic field is so powerful that even at a distance of 1,000km (620mi) it would still be bad news for life, distorting molecules.

Heavyweight champion
They might only have a diameter of 16km (10mi), but magnetars are much heavier than our Sun.

Living a short life
The powerful magnetic fields these rapidly spinning stars exude are very short-lived. After about 10,000 years the magnetar becomes increasingly powerless.

How were magnetars discovered?

In March 1979, after dropping satellites onto the surface of Venus, two Soviet spacecraft were sent drifting though the Solar System when they were all of a sudden blasted by an immense burst of gamma radiation, causing the readings on both probes to skyrocket from 100 counts per second on to over 200,000 counts per second. The numbers jumped in almost an instant, or mere fractions of a second.

Amazed and somewhat bemused by the finding, scientists followed up on the mysterious blast that saturated the likes of NASA's Helios 2 probe, the Pioneer Orbiter around Venus and, mere seconds later, many satellites orbiting our own planet. The radiation seemed to seep in everywhere, which made it easier for astronomers to work out where it was coming from. Narrowing the direction down, they figured out the radiation was coming from a magnetar made by a star that had gone supernova around 3000 BCE.

They can spin slow or fast

We know magnetars spin incredibly fast, but what's more interesting is that they're also capable of putting on the brakes, so to speak, and slowing themselves down. It's an interesting observation but it's also one that can't be easily explained by our existing theories of physics, making the magnetar even more mysterious.

That's not to say that astronomers haven't had some intelligent guesses as to what could be causing the behaviour they refer to as the "anti-glitch issue." They speculate there are pockets of fluid inside the star that's rotating faster and faster until it's sloshing around much faster than the stellar crust on the surface. Of course, this theory has not been proven yet, but scientists are beginning to wonder if these disturbances cause a magnetar's crust to crack, leading to their decline.

© Science Photo Library

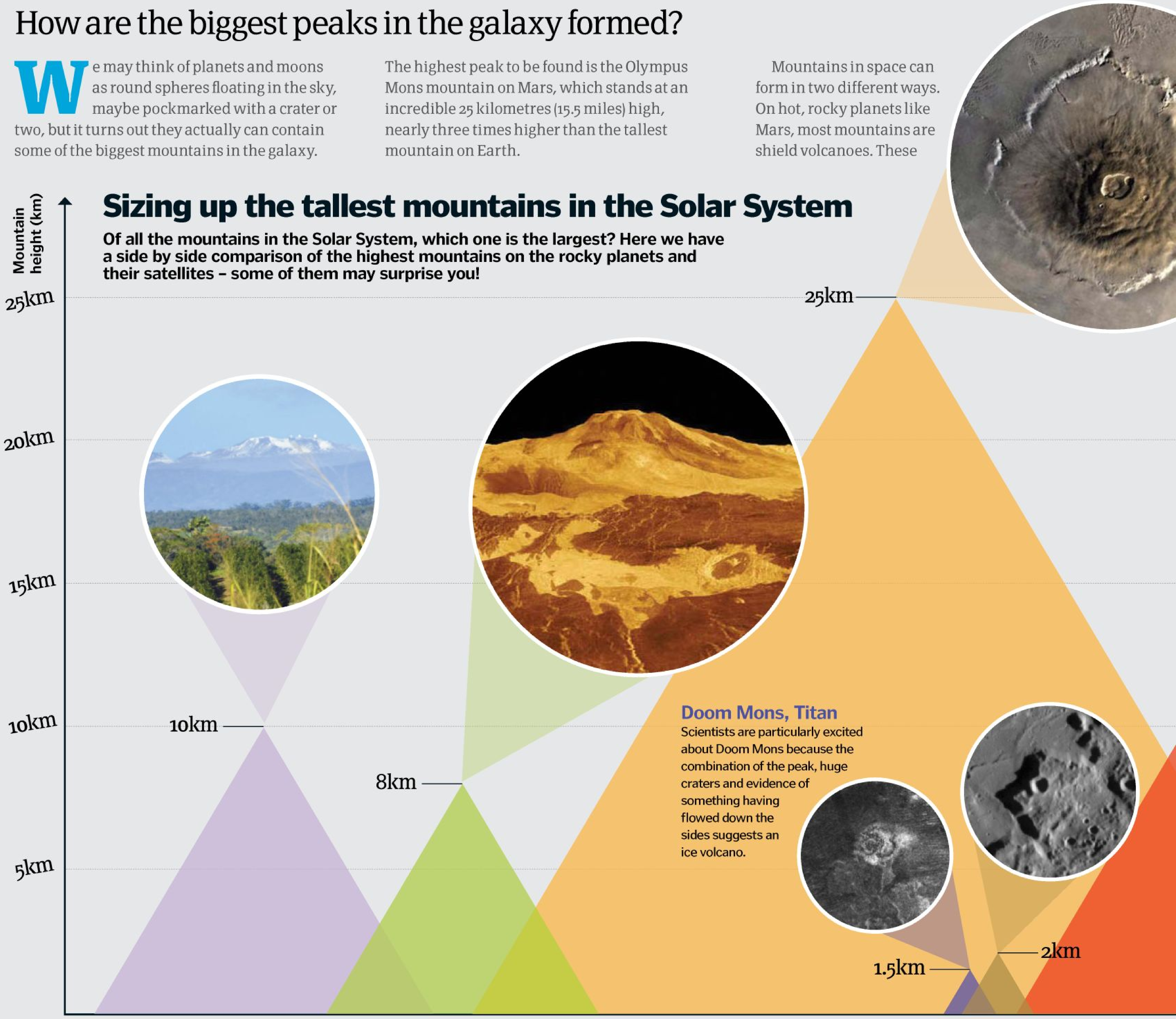
How are space mountains created?

How are the biggest peaks in the galaxy formed?

We may think of planets and moons as round spheres floating in the sky, maybe pockmarked with a crater or two, but it turns out they actually can contain some of the biggest mountains in the galaxy.

The highest peak to be found is the Olympus Mons mountain on Mars, which stands at an incredible 25 kilometres (15.5 miles) high, nearly three times higher than the tallest mountain on Earth.

Mountains in space can form in two different ways. On hot, rocky planets like Mars, most mountains are shield volcanoes. These



Sizing up the tallest mountains in the Solar System

Of all the mountains in the Solar System, which one is the largest? Here we have a side by side comparison of the highest mountains on the rocky planets and their satellites – some of them may surprise you!

Doom Mons, Titan
Scientists are particularly excited about Doom Mons because the combination of the peak, huge craters and evidence of something having flowed down the sides suggests an ice volcano.

Mauna Kea, Earth
Topping Everest because so much of it is underwater, Mauna Kea is a dormant volcano in Hawaii that houses many NASA telescopes.

Maat Mons, Venus
This mountain has lava stretching for hundreds of kilometres down the shallow slopes, typical of a shield volcano, made up of solidified lava.

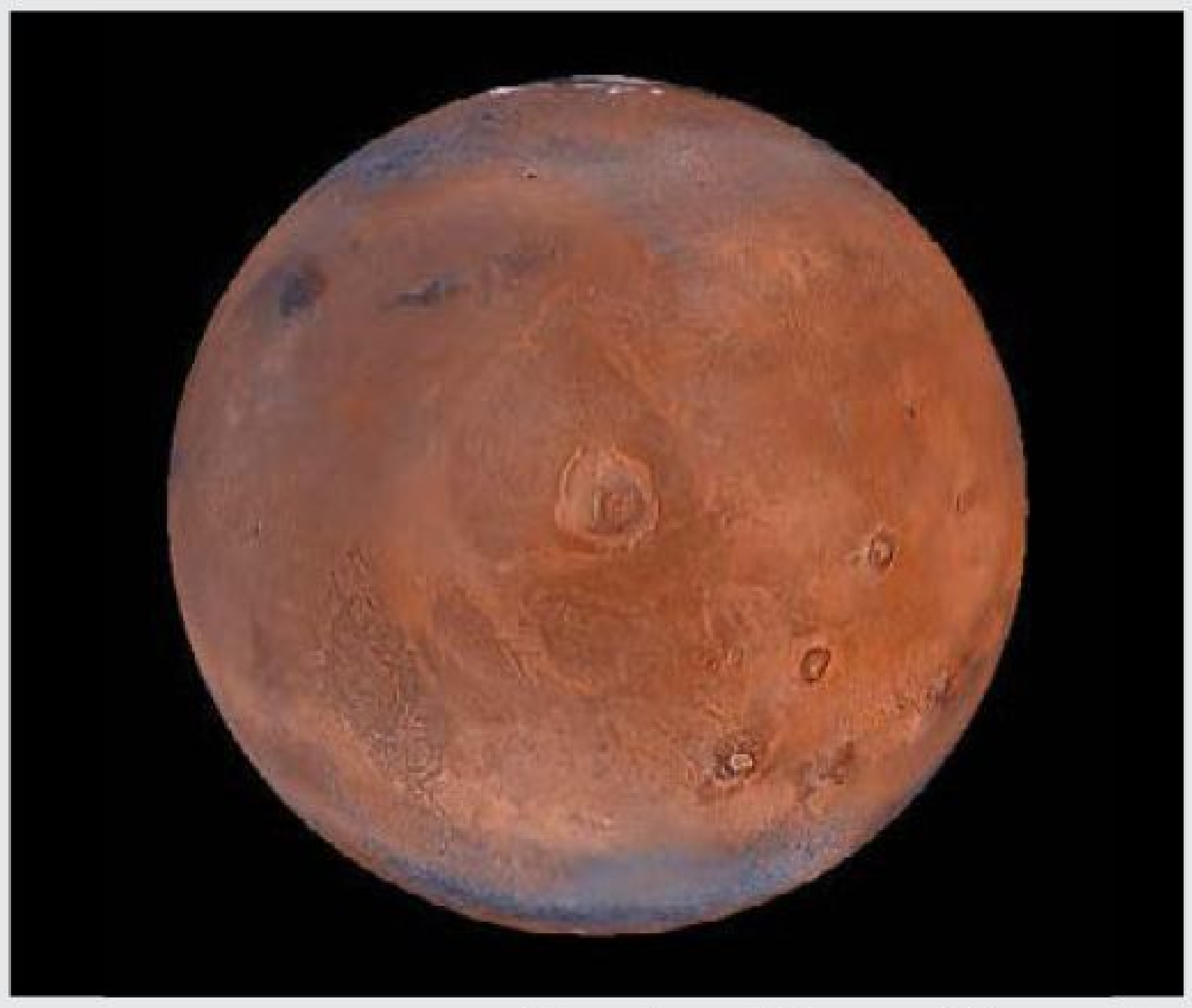
Olympus Mons, Mars
The tallest mountain in the galaxy is a potentially active shield volcano. Part of it formed over billions of years while some parts may only be a few million years old.

Caloris Montes, Mercury
This mountain ring is made up of bedrock disturbed by a huge impact that created the Caloris Basin. The rocks settled and became mountains.

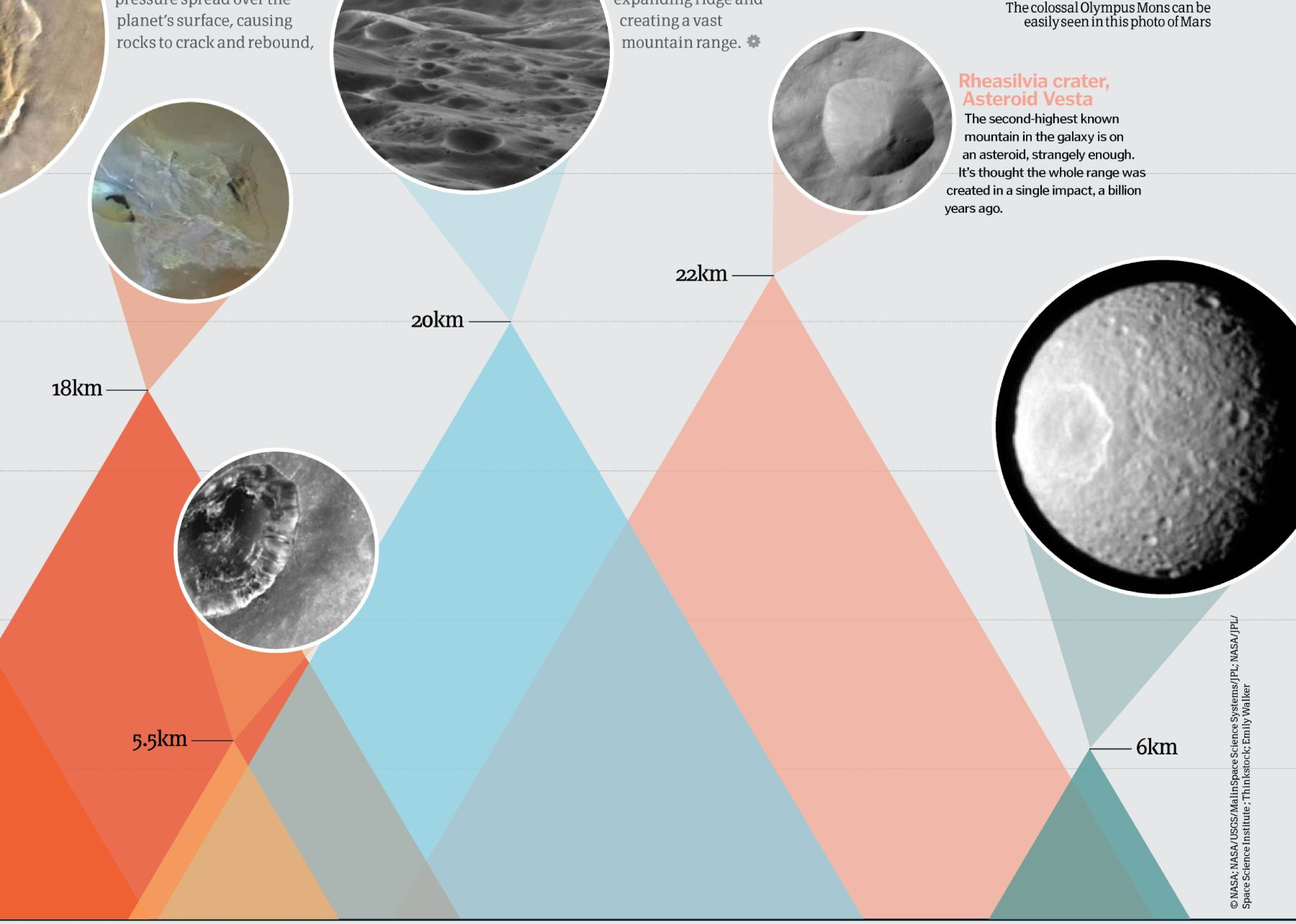
develop like volcanoes do on Earth, with extreme pressure under the crust pushing up to form a peak. Lava then flows down the sides of the volcano before solidifying. The thin layers of lava gradually form the characteristic profile of a shield volcano. These are 'self-growing' mountains and they will continue to grow as long as lava flows from them.

This is not the case for other common types of space mountains, which are formed due to high impact. When a meteor or asteroid collides with a moon or planet, a crater is formed. Shock waves of increased temperature and pressure spread over the planet's surface, causing rocks to crack and rebound, forming a peak around the crater edge. An example of a crater mountain is the Herschel Crater on the Saturn moon Mimas. We're able to see these mountains thanks to incredibly sharp telescopes on Earth, while those farther afield are captured on cameras mounted on spacecraft as they fly by their targets.

Finally, there is the equatorial ridge on Saturn's moon Iapetus. The current theory is that rocks and space debris were trapped in the moon's gravitational field, pulled towards it and became stuck to the planet, forming an ever-expanding ridge and creating a vast mountain range.



The colossal Olympus Mons can be easily seen in this photo of Mars



Rheasilvia crater, Asteroid Vesta
The second-highest known mountain in the galaxy is on an asteroid, strangely enough. It's thought the whole range was created in a single impact, a billion years ago.

Boosaule Montes, Io
Jupiter's third-largest moon is home to this vast mountain, created by pressure built up under the moon's crust that pushed their way upward.

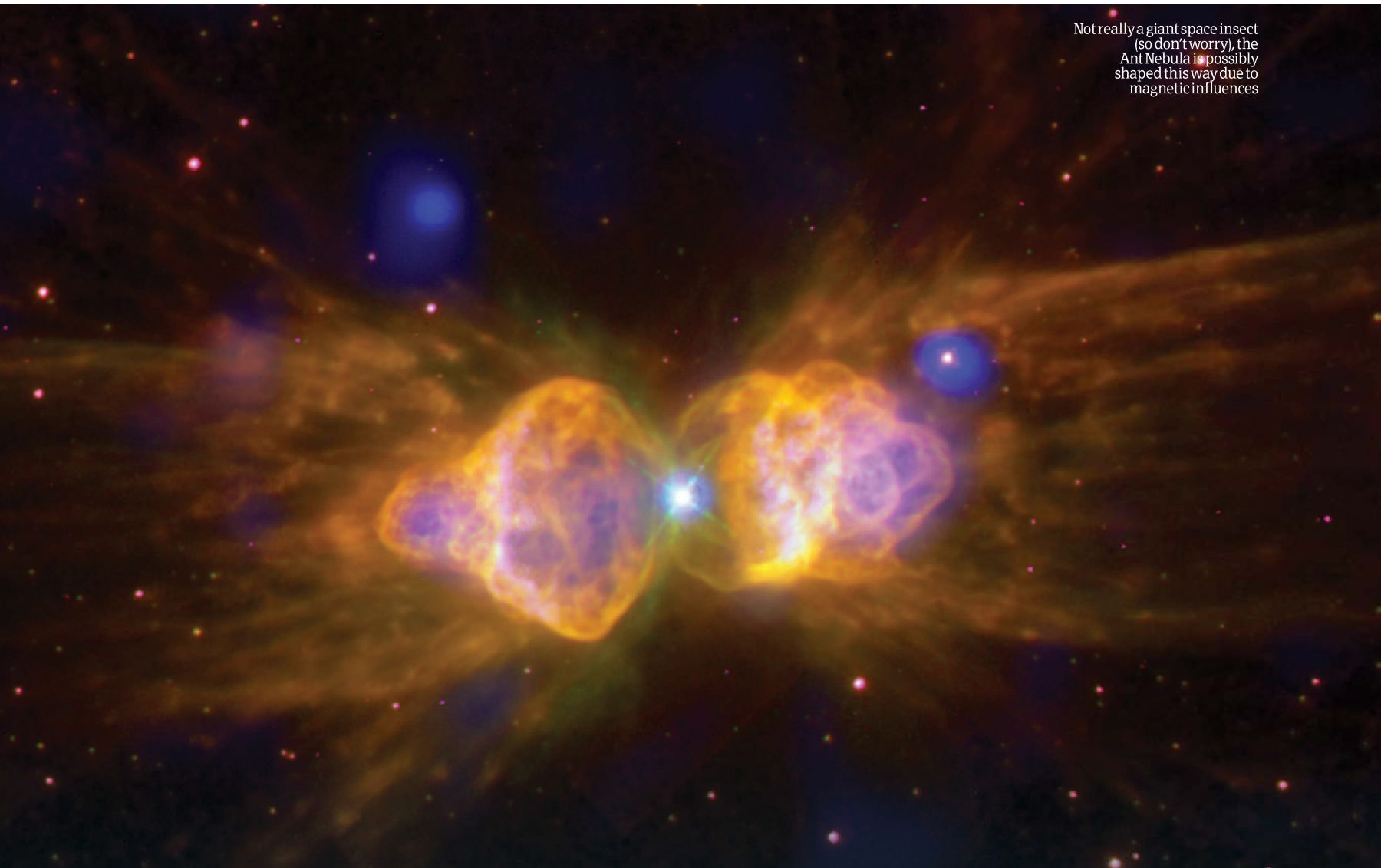
Mons Huygens, Moon
The highest mountain on the Moon is named after Dutch astronomer Christiaan Huygens and is found in the Montes Apenninus mountains.

Equatorial Ridge, Iapetus
It is thought the equatorial ridge around Saturn's third-largest moon isn't actually from the planet but was dragged there by gravity and became part of the moon.

Herschel Crater, Mimas
Rising up from the centre of one of the largest craters in the Solar System is a mountain created by the force of an impact on this Saturnian moon.

Mountain name and location

© NASA; NASA/USGS/MalinSpace Science Systems/JPL; NASA/JPL/Space Science Institute; Thinkstock; Emily Walker



Not really a giant space insect (so don't worry), the Ant Nebula is possibly shaped this way due to magnetic influences

What can the Ant Nebula teach us?

Why this fascinating view offers an insight into what our Sun may become

The Ant Nebula is one of the most intriguing phenomena in our galaxy. Around two light years in diameter it is located around 3,000 light years away from our Solar System, in the constellation of Norma.

The nebula is the result of the death of a star similar to our Sun, but what has intrigued astronomers across the globe is the peculiar shape it has taken on. With a bulge either side of the star, the nebula resembles an ant, the two lobes looking like the head and thorax.

Scientists still aren't 100 per cent sure as to how this space insect formed. Normally, once a star reaches the end of its life, it violently expels gas into the void of space. However, the Ant Nebula hasn't managed to entirely let go of its gaseous material. Some theories as to why this unique event has occurred include a second, hidden star orbiting Menzel 3 (the proper name for the Ant Nebula), holding the gas in close proximity. Another theory suggests that the star itself is holding the gas close with its own magnetic field. The rotation of the star causes the magnetic field to fluctuate, but without letting the gas get too far away.

One of the other reasons for keeping a close eye on Menzel 3 is to get an insight of what might happen to our Sun when it starts to die, some 5 billion years from now. Interestingly close examination of the nebula shows a controlled, symmetrical pattern of flowing gas – very different from the chaotic swirls that scientists would expect to see. ✿

© Alamy

Can there be life on exomoons?

How humans could begin to colonise moons in other solar systems

Exploring the universe was once the stuff of science fiction, but exomoons could change that. Orbiting exoplanet gas giants similar to Jupiter or Saturn, these moons are comparable to the likes of Europa, Titan and Enceladus in our Solar System. These three natural satellites are believed to have the best chance of supporting life so scientists hold similar worlds in a very high regard.

Encouragingly, as they orbit gas giants, the exomoons are around the size of Earth. There are two main techniques in finding an exomoon. Firstly, if there is a slight dip in brightness this could show a celestial body crossing in front of a star. Secondly, the gravitational pull from a possible satellite can cause light to bend around it, momentarily magnifying it like a lens. None have officially been discovered yet but 250 potential exomoons have been located.

Currently, the HEK (Hunt for Exomoons with Kepler) project is in place and in 2018, NASA will launch the James Webb Space Telescope to study them further. To be habitable for humans they must have the correct conditions for carbon-based life forms to survive. Experts theorise that binary solar systems (systems with two stars) are more likely to have moons suitable for life. This is because binary stars dampen each other's solar radiation, which creates better conditions for life.

Eccentric orbits can put moons briefly out of the habitable zone but planetary illumination and tidal heating make them still momentarily sustainable. On the downside, even the nearest planets are still too far away for human expansion with current shuttle and rocket technology, so exomoons are still a pipe dream for the foreseeable future. Let's just stick to Mars for now… ✻

The four states of a celestial body

All planets and moons have different life-span stages. These phases are known by scientists as 'habitable', 'hot', 'snowball' and 'transient.' The first sort has temperatures that stay more or less at the same average level, with more than ten per cent of the surface between the freezing and boiling point of water. The second, as its name suggests, has temperatures of a scorching 100 degrees Celsius (212 degrees Fahrenheit) minimum unlike snowball, which is constantly frozen. Transient is slightly different from the others as it has habitable conditions but varies in the amount of inhabitable surface area.

Can we farm in space?

Growing intergalactic plants could be the key to living in space

One of the big hurdles to long-haul space flight and possible space colonisation is the absence of foodstuff in deep space. At the moment, astronauts are limited to dry processed food but methods are being developed to grow vegetation or 'space salad.'

The first forays into intergalactic farming are being pioneered by NASA tests at the ISS (International Space Station) and the Kennedy Space Center, as well as The International Laboratory of Plant Neurobiology. They all aim to devise ways for a terrestrial body to adapt to extraterrestrial conditions.

Initial tests have used lettuce as it can be eaten without being heated and is easy and simple to grow, but lack of gravity in space could be an issue. Artificial soil would float away and water wouldn't drain. Solutions to this include a 'plant pillow' which has grow bags to hold the soil in place and a permeable fabric to guide the water to the plant's roots.

For now, plants will be grown hydroponically – in nutrient solution instead of soil – with red and blue LEDs providing light for photosynthesis. As well as being a food source, plants will also help enrich alien worlds with oxygen and reduce toxic levels of carbon. The aim is to produce an artificial ecosystem, called bioregenerative, to sustain astronauts for long voyages and missions. ✻

Plants grown in controlled conditions will form the nutritional requirements for astronauts on major expeditions

What are meteorites?

Understanding the space rocks that survive the fall to Earth

Earth-bound space rocks have gone down in history as terrifying missiles that will wipe us all out, according to countless disaster movies, but what exactly are these great falling balls of fire?

Essentially, chunks of rock that have been chipped off from asteroids after collisions with obstructions in space – whether that be another asteroid, spacecraft or satellite – are called meteoroids. Occasionally, they can even be from the Moon or Mars, both of which can be identified as they are much younger than asteroid meteoroids.

It's all relative, though, as these 'young' meteoroids can still be an incredible 2.5 billion years old. They continue spinning through space until they are pulled into the gravitational field of a planet, like Earth. As they travel through the Earth's atmosphere in a dazzling streak of light across the sky, they are called meteors or shooting stars.

Any that are able make it all the way through the atmosphere and down to the Earth's surface are called meteorites. If these are large enough, they can strike with a great deal of force, forming huge craters. These vast cavities are still providing scientists with useful data, such as when they landed and the impact they had on the Earth when they did.

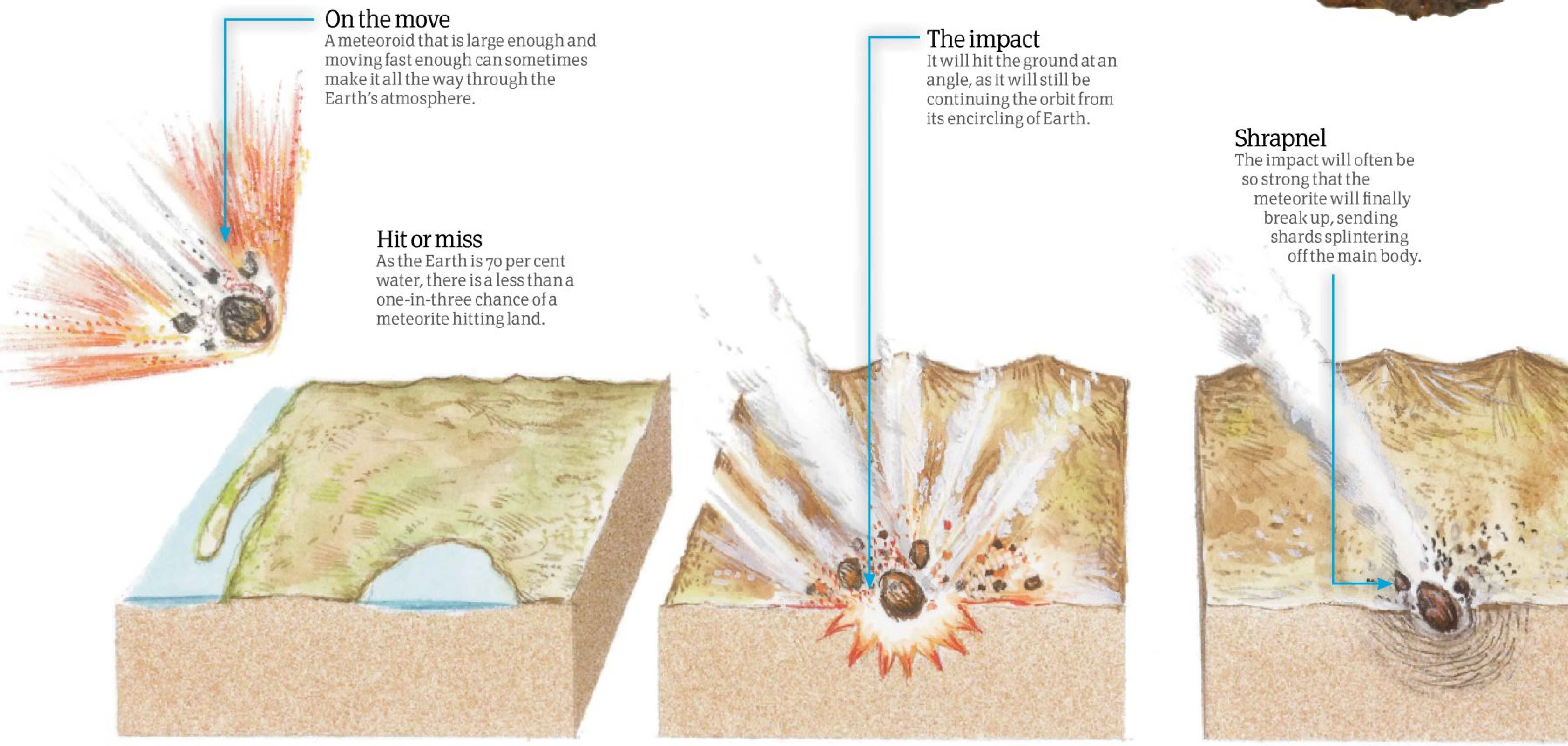
The most famous of all space rock strikes to hit Earth would have to be the one that wiped out the dinosaurs. When a ten-kilometre (6.2-mile) wide asteroid crashed into South America around 66 million years ago, it triggered volcanic eruptions, tsunamis and mammoth earthquakes that threw dust into the atmosphere and blocked out the sunlight. A planet-wide freeze followed, sending temperatures plummeting and decimating plant and animal life.

Fortunately, institutions like NASA have early warning systems in place that can track the path of meteorites for years before there is even the faintest chance of one colliding with Earth, so we should be safe from a real-life and catastrophic Armageddon event.

A meteorite found in Arizona, USA

When meteorites attack

What happens when a meteoroid is large enough to survive the journey through the atmosphere?


On the move
A meteoroid that is large enough and moving fast enough can sometimes make it all the way through the Earth's atmosphere.

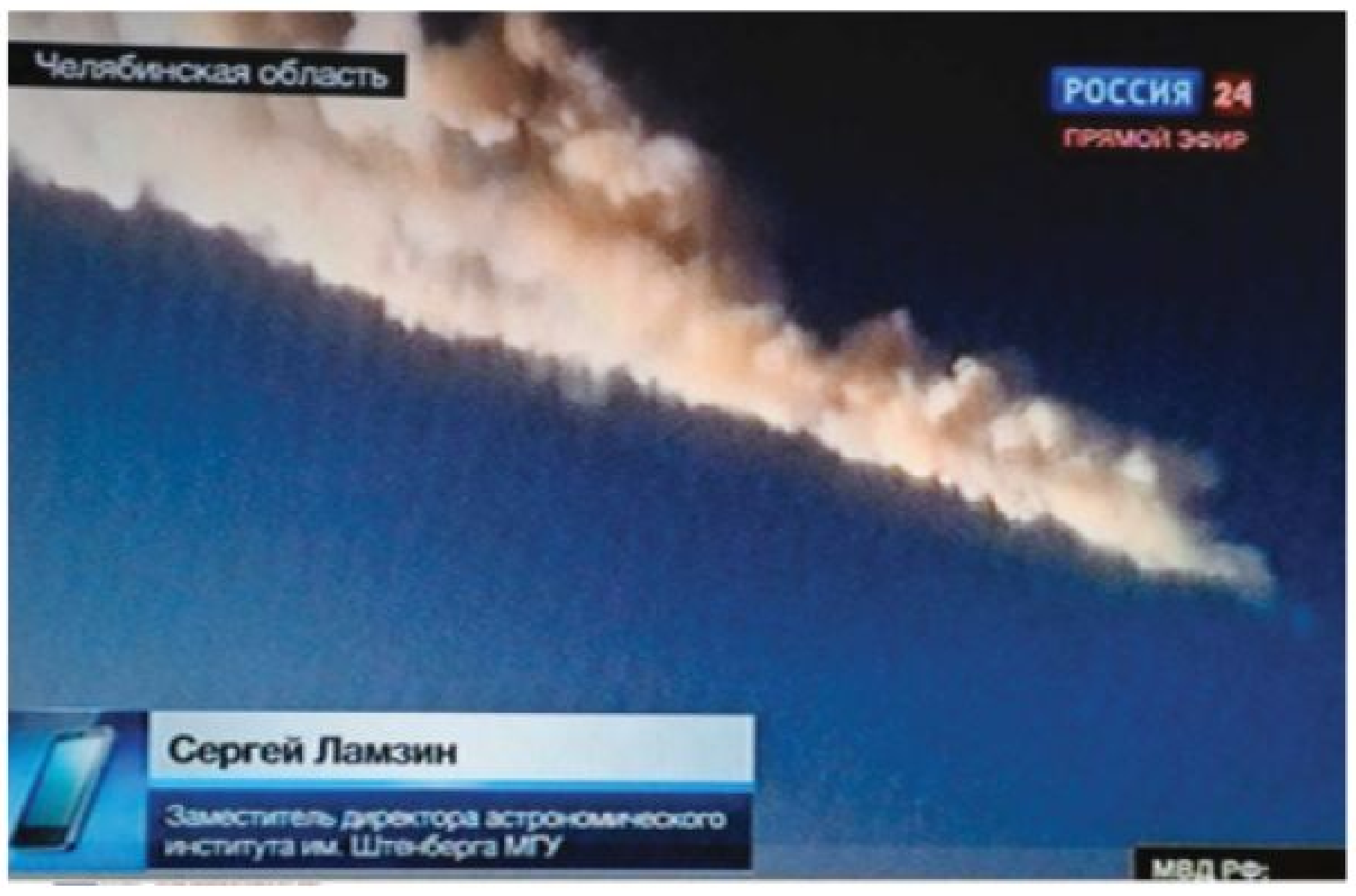
Hit or miss
As the Earth is 70 per cent water, there is a less than a one-in-three chance of a meteorite hitting land.

The impact
It will hit the ground at an angle, as it will still be continuing the orbit from its encircling of Earth.

Shrapnel
The impact will often be so strong that the meteorite will finally break up, sending shards splintering off the main body.

Meteor explosion over Russia caught on film

Fireball causes skin and retinal burns

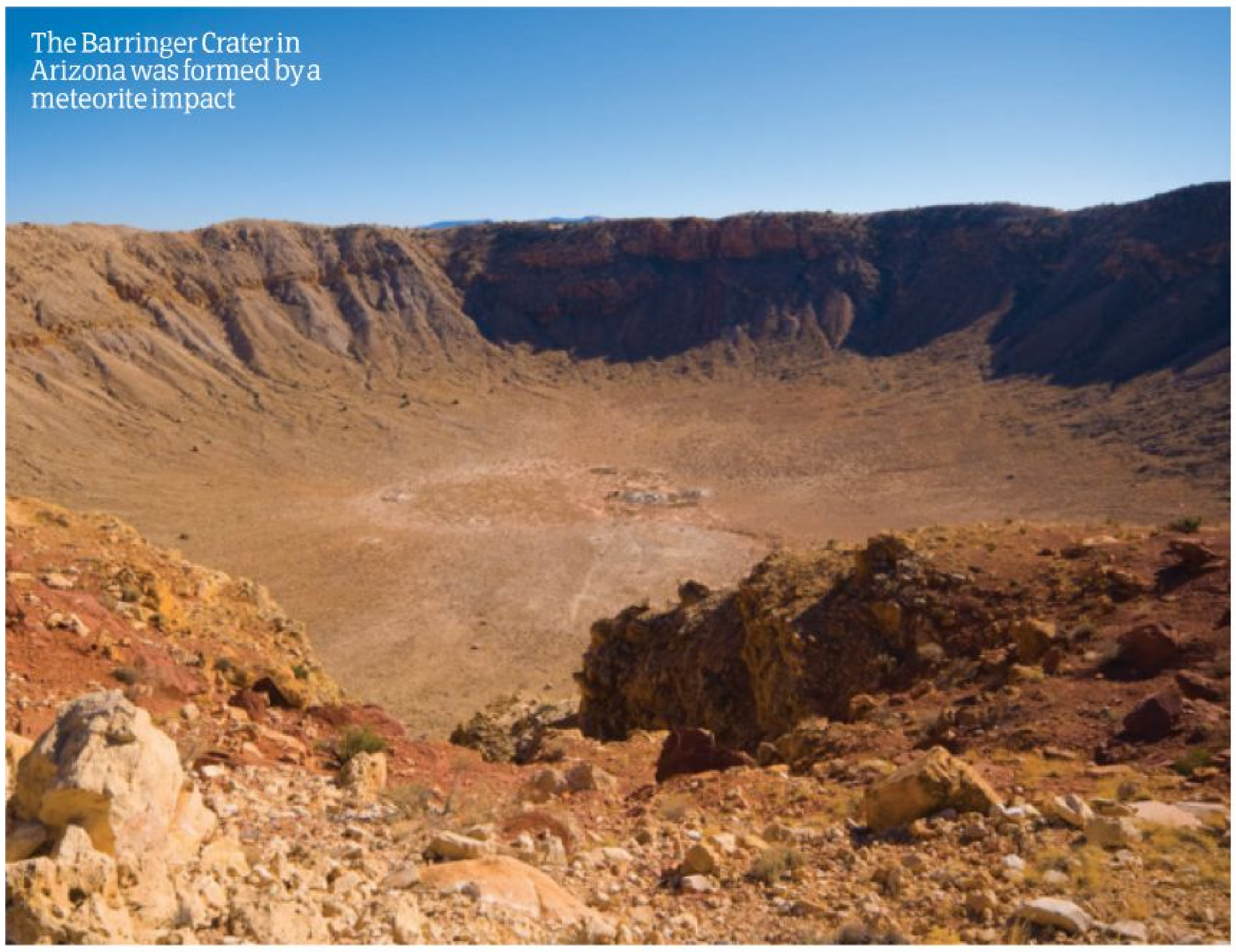

Челябинская область
РОССИЯ 24
ПРЯМОЙ ЭФИР
Сергей Ламзин
Заместитель директора астрономического института им. Штенберга МГУ
МВД РФ:

In February 2013, the citizens of Chelyabinsk in Russia had a close shave with disaster when a 17-metre (56-foot) long meteor broke up over their city.

The space rock weighed an amazing 10,000 tons and tore through the sky, injuring over 1,000 people, despite not actually coming into contact with anything until it broke through the ice on top of Lake Chebarkul.

Injuries sustained included skin and retinal burns from the intense heat and light, as well as being hit by glass and debris blown out from the blast, which was the equivalent of 500 kilotons of TNT exploding.

Although it fortunately landed in water, the fact that it caused so much destruction without even touching land shows the incredible power these asteroid offshoots can cause. A quick internet search will bring up several must-see videos of the meteor and the effects it had.

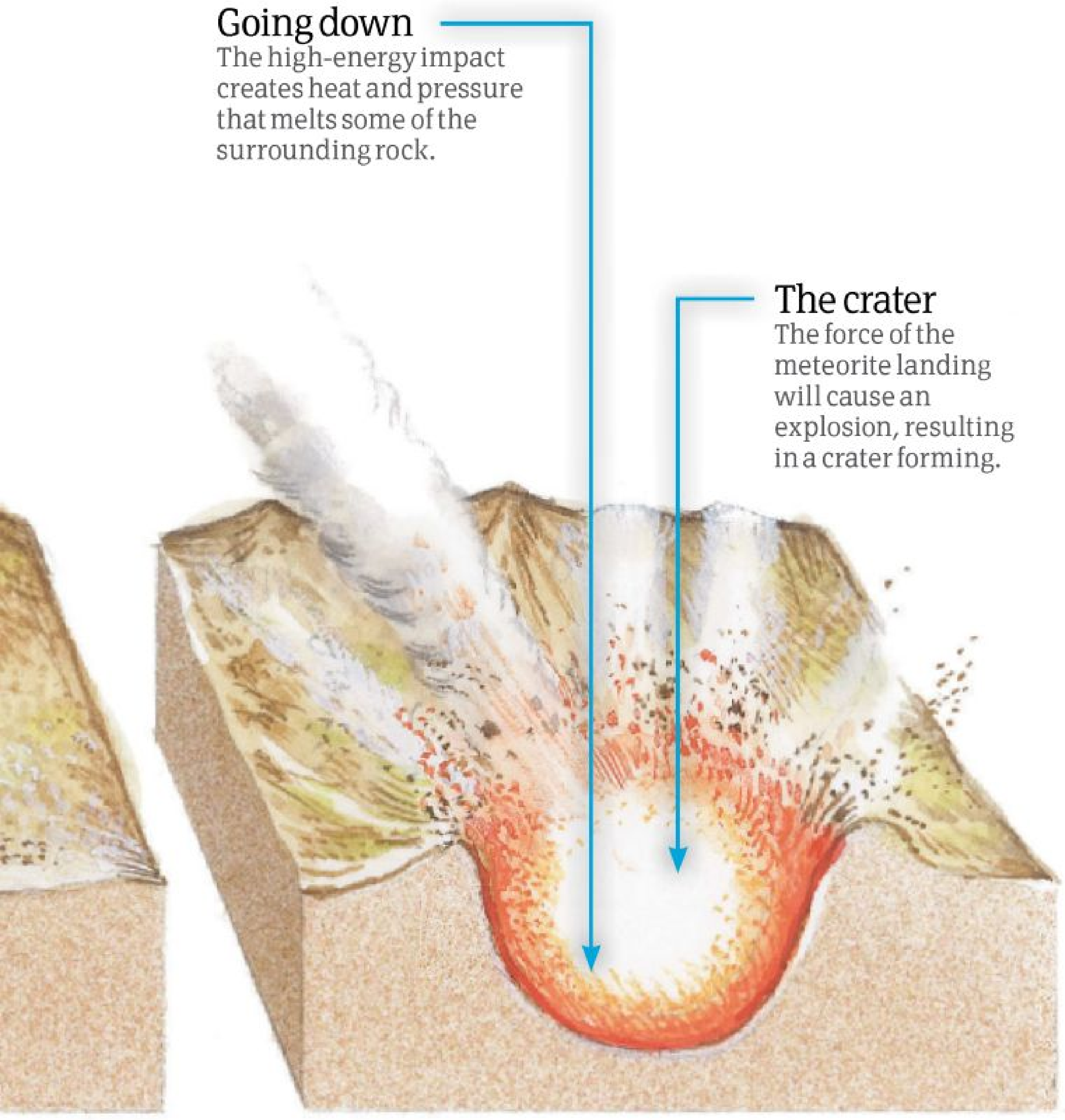


The Barringer Crater in Arizona was formed by a meteorite impact

Shooting stars

A shooting star is one of the most incredible things you can see in the night sky and a shower of them is required viewing for all budding astronomers. What you're seeing is not actually a star at all, however, but in fact the final moments of a meteor that has entered Earth's atmosphere and is burning up in the super-hot environment.

Around 100 tons of material and space debris enters Earth's atmosphere every day, but most of it is much too small to see from the surface. Hence a meteor shower is a once-a-year event, only occurring when the Earth passes through an area of space particularly heavy with meteors, resulting in a sky full of dazzling shooting stars.

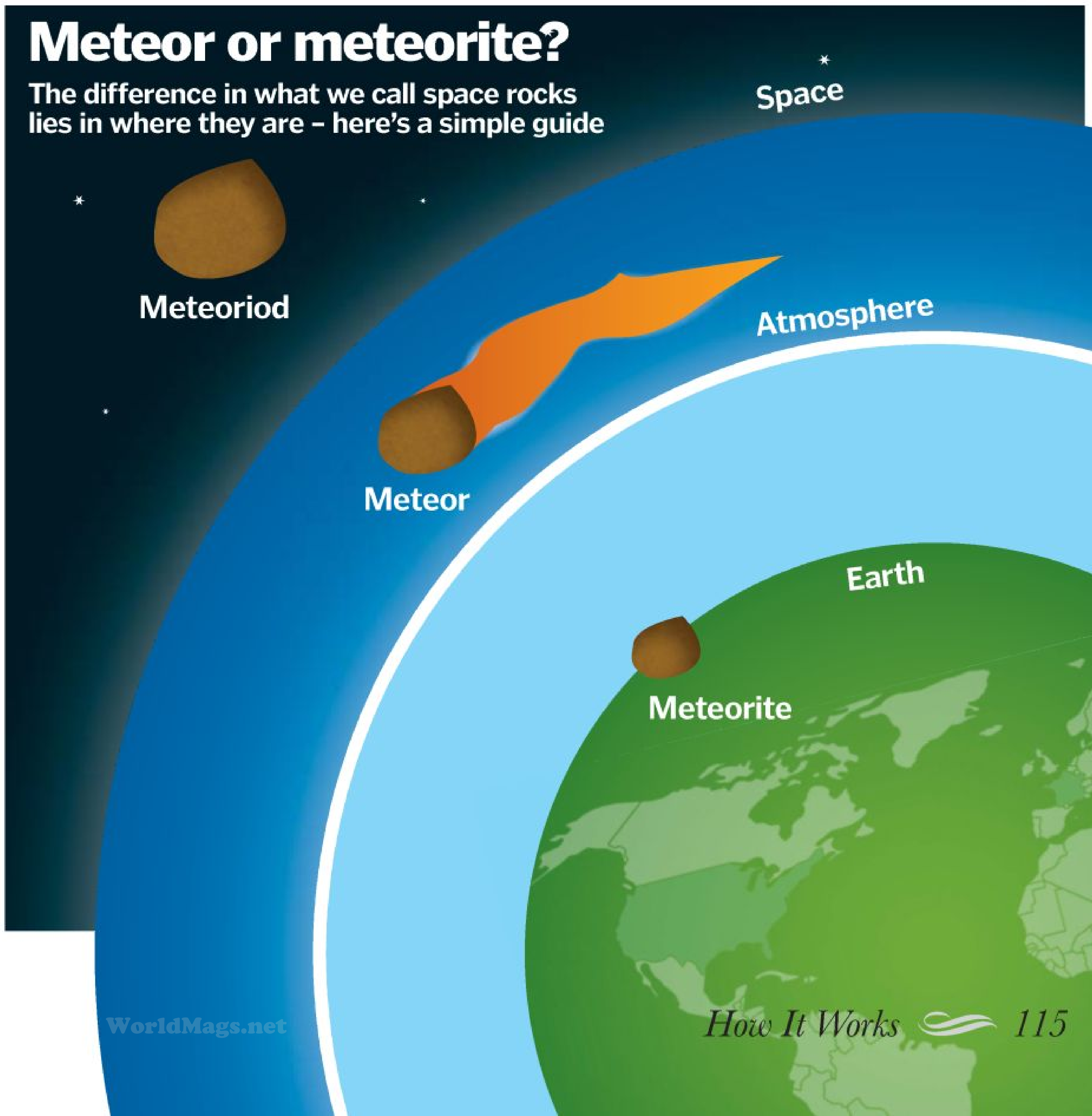


Going down
The high-energy impact creates heat and pressure that melts some of the surrounding rock.

The crater
The force of the meteorite landing will cause an explosion, resulting in a crater forming.

Meteor or meteorite?

The difference in what we call space rocks lies in where they are – here's a simple guide



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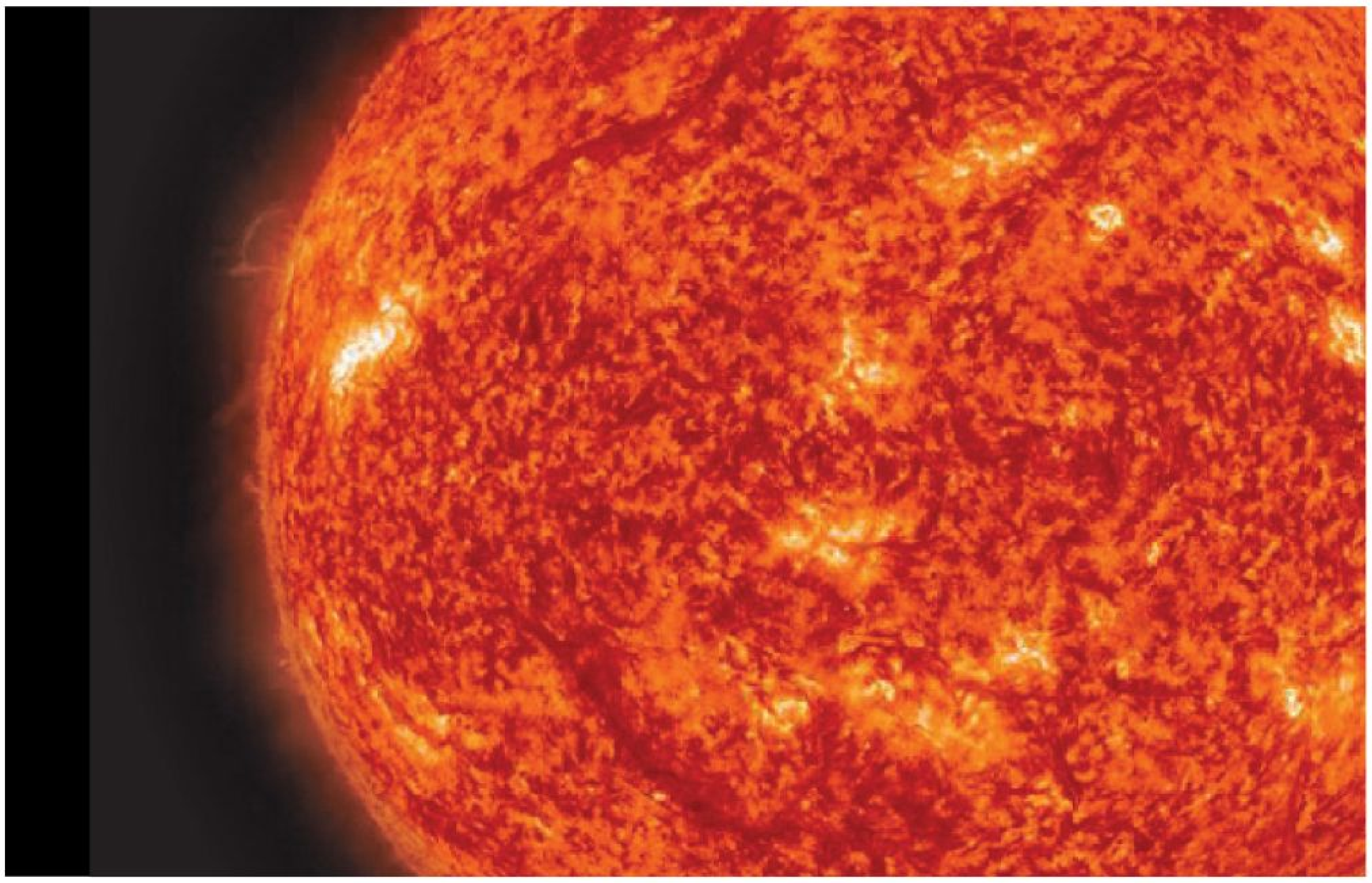
Why are there 'seas' on the Moon – did it once have water?

The term 'seas' (or in Latin, maria) was invented by German astronomer Johannes Kepler in 1610, shortly after the invention of the telescope. Kepler, like many before him, thought that the dark patches on the surface of the Moon were bodies of water similar to Earth's oceans, but within a few years, improvements to telescopes showed that this was not the case – the 'seas' are actually smooth dark plains pockmarked by occasional craters. Today we know the 'seas' are actually solidified remains of huge lakes of lava that erupted onto the Moon's surface more than 3 billion years ago and filled in low-lying impact basins created by earlier collisions. So the lunar seas were never filled with water – but there's still good evidence for water ice, brought to the Moon by comets, buried in the ground close to our satellite's cold poles.

If you get diamonds on other planets, are there other gemstones too?

Diamonds are probably common on other planets because they're made of pure carbon, and carbon itself is a common element throughout the universe. Chemistry works in the same way on other planets, but other gemstones have more complex structures involving a variety of elements (some of which are much rarer than carbon), so Earth-like gems and minerals might only occur on Earth-like planets. Many gemstones also form only in the presence of water, so they would require a wet, Earth-like environment to develop.



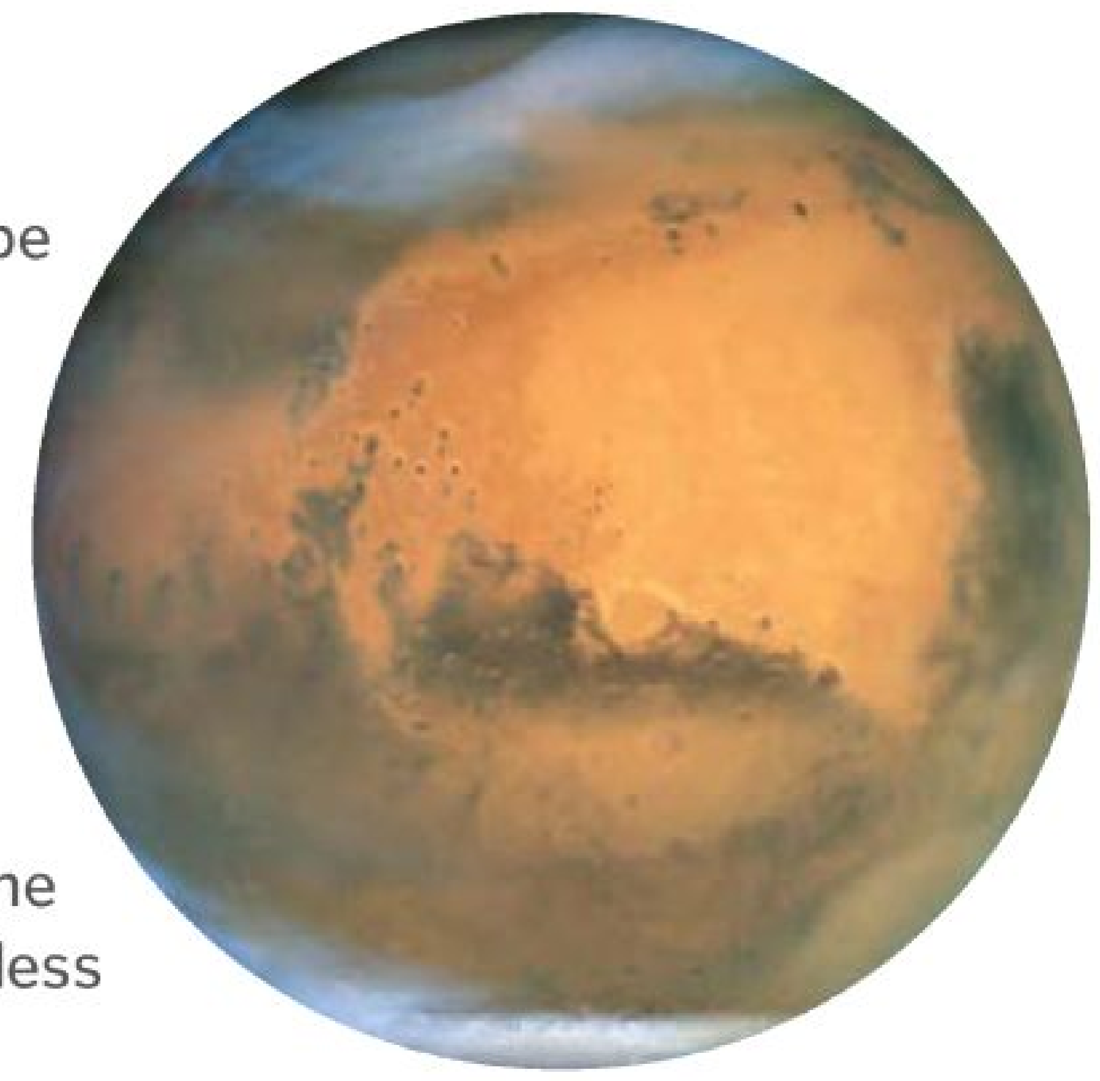
Could the life of a star be extended by human intervention?

Stars like the Sun age and eventually die because of the limited amount of fuel available in their central core. The core is the only region where conditions are hot and dense enough to trigger nuclear fusion and convert hydrogen into helium – the main power source for most stars. But even when a star has replaced most of its core hydrogen with helium (in another 5 billion years or so for our Sun), and begins to swell and become a red giant, vast amounts of hydrogen remain untouched in the outer 'envelope' around the core. With sufficiently advanced technology, future humans might be able to prolong the Sun's life by churning up the Sun's interior and feeding more hydrogen into the core to refresh its fuel supply. This sort of event happens naturally when stars collide and merge, but we might be able to develop a less drastic way of doing it.

> "The core is the only region where it's hot and dense enough to trigger nuclear fusion"

Do any planets other than Earth experience seasons?

Yes, plenty! For a planet to have seasons as we normally perceive them, its axis of rotation must be tipped over at an angle, so that the amount of sunlight reaching different parts of its surface changes as it orbits the Sun. In our Solar System, Mars (right), Saturn and Neptune all have axes tilted at roughly the same angle as Earth's, so they experience a similar cycle of spring, summer, autumn and winter (though over a much longer period). Uranus is tipped over at a much sharper angle so it experiences even more extreme seasons, while Jupiter, Venus and Mercury are more or less 'upright', and don't experience seasons.

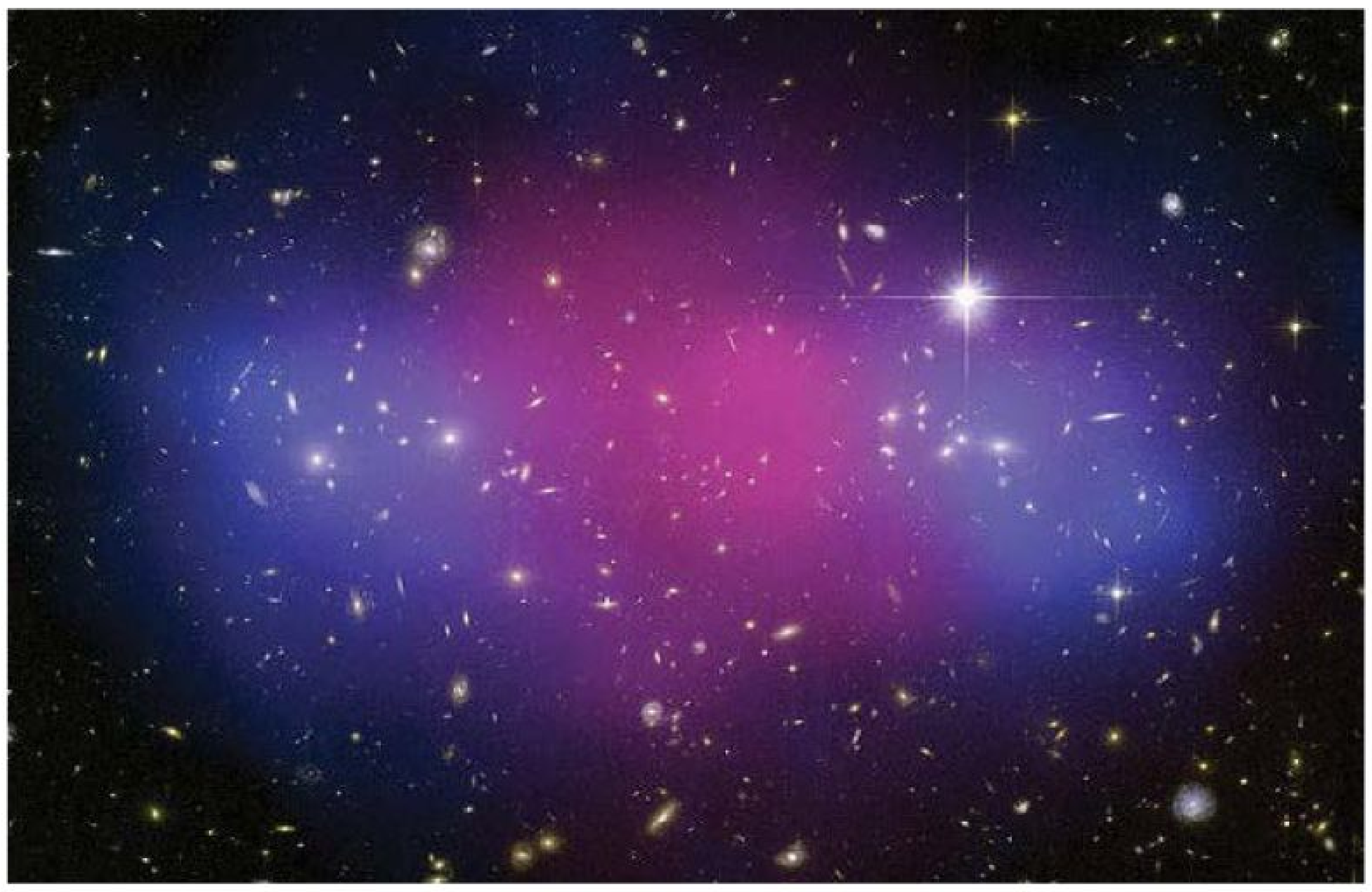


Has a comet ever hit our planet?

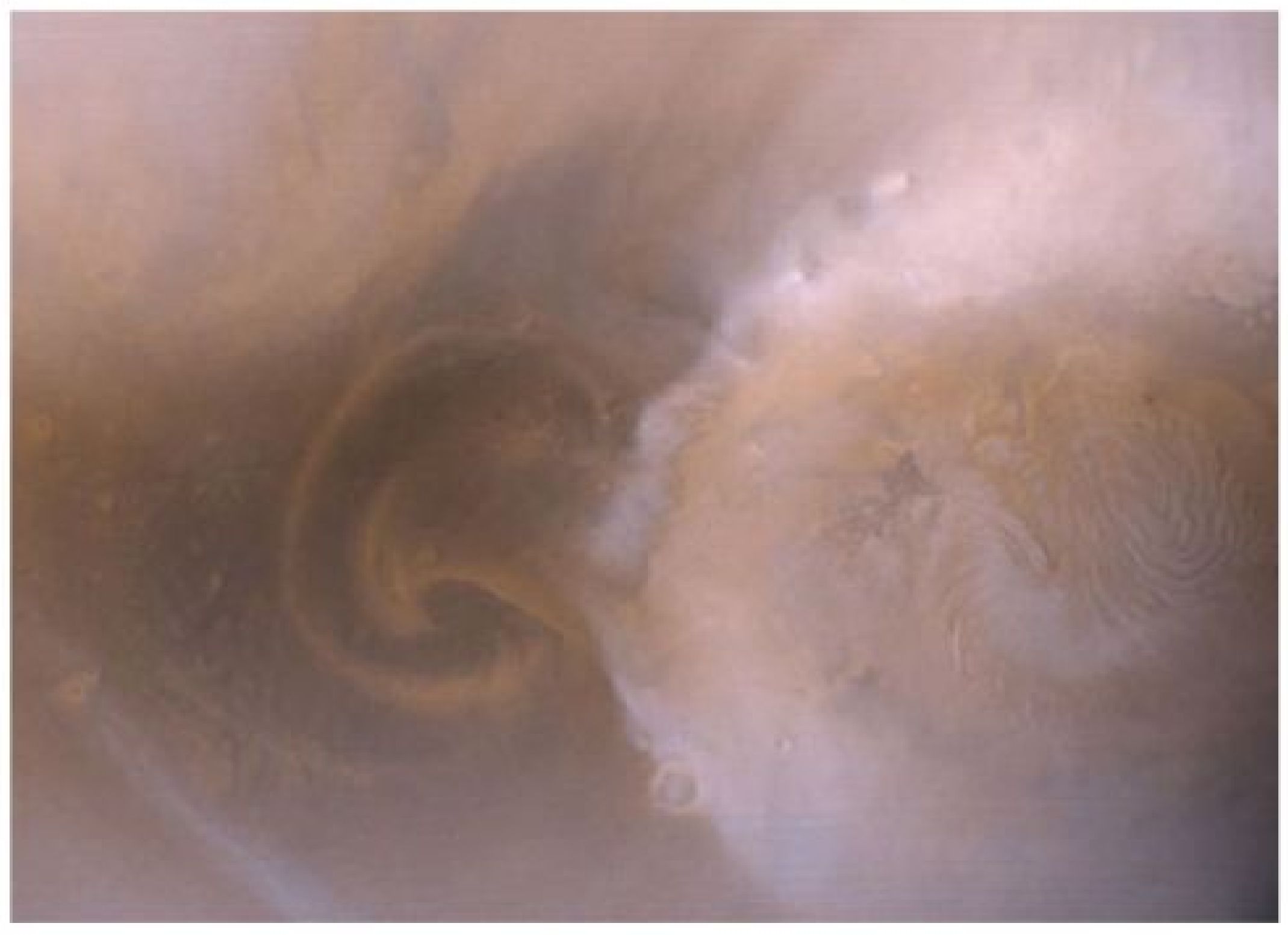
Yes – on a cosmic timescale, comets hit the Earth frequently, but because they're largely made of ice rather than solid rock, they tend not to leave obvious craters. A small comet is more likely than an asteroid to break up as it plunges into Earth's atmosphere and heats up, often resulting in an explosion called an airburst that can devastate large areas of the landscape but doesn't leave a crater. Perhaps the most famous such event happened over the Russian region of Tunguska in 1908, when an exploding comet flattened some 2,000 square kilometres (770 square miles) of Siberian forest. A comet would have to be pretty big in order to hit the ground intact.

What are galactic clusters?

A galaxy cluster is any group of galaxies whose gravity is enough to overcome the general expansion of the universe and hold it together. About half of all galaxies are found in clusters of one sort or another. The least impressive clusters, known as galaxy groups, typically contain a handful of large systems surrounded by a few dozen smaller dwarf galaxies – our Milky Way galaxy, for example, is one of three large spirals in the so-called Local Group. Dense clusters, however, may contain up to a couple of thousand galaxies including dozens of large spirals and elliptical (ball-shaped) galaxies. Curiously, the size of the different types of galaxy clusters does not vary all that much – they always seem to be around one to ten megaparsecs (or 3-33 million light years) across.



Where do the biggest dust storms occur?



Mars is home to the largest and most powerful dust storms ever recorded. Martian dust storms have been known to engulf the entire planet in a haze for months at a time, making it difficult to single out one as being the biggest. Dust and sandstorms on Mars and Earth happen due to temperature differences in the atmosphere. Hot air moves to colder air, and this moving air can pick up tiny debris in arid landscapes. It is not known exactly why storms on Mars can spread so far, however the fact it is such a dusty world probably has something to do with it!

* * *

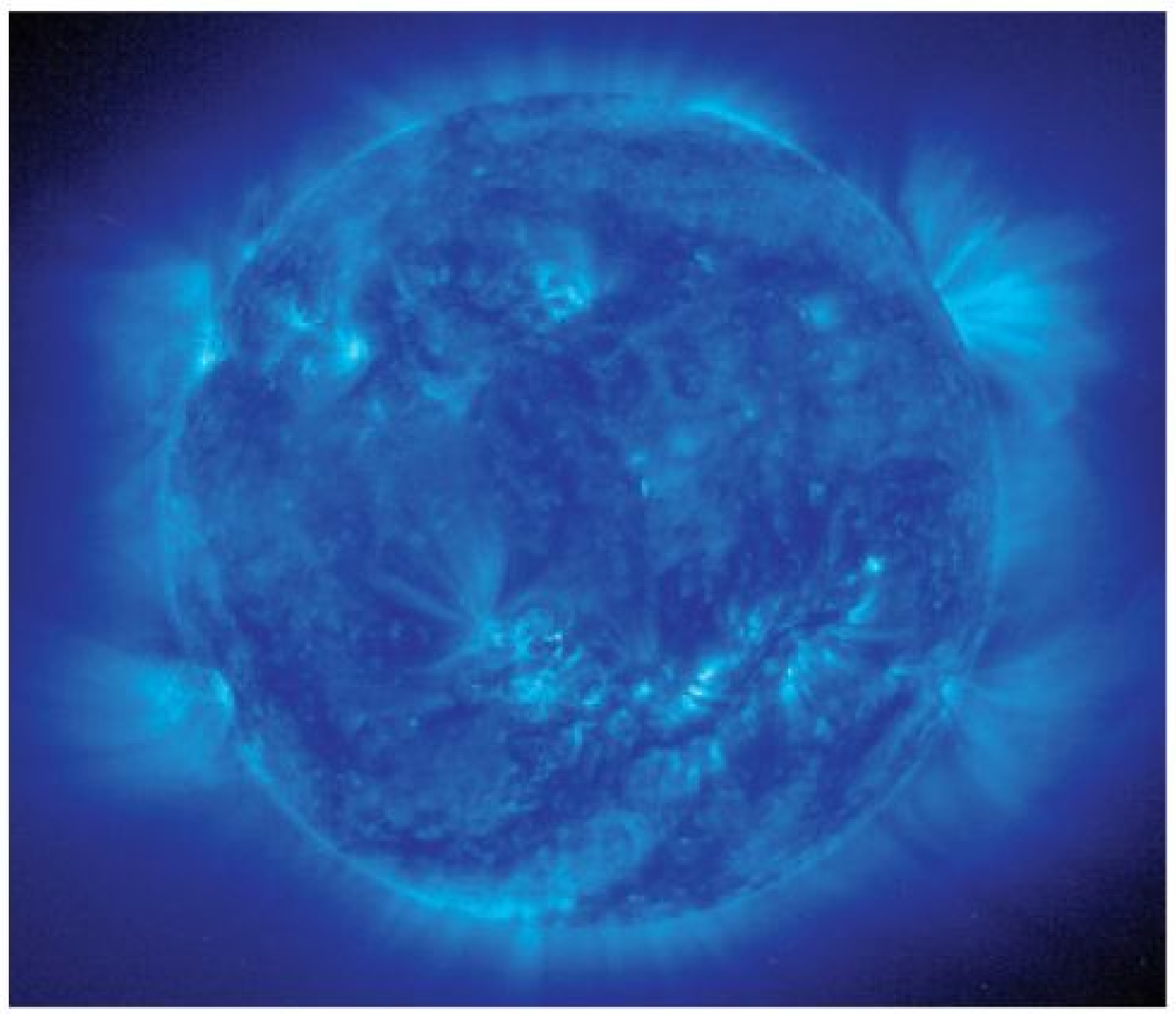
Would anything be different on Earth if we had two moons orbiting us?

In order to remain stable in its orbit, a second moon of Earth would have to sit at one of the Lagrangian points – sweet spots where the gravitational forces of Earth and Moon partially neutralise each other. The second moon's gravitational tug on Earth would increase its tides, either complicating their pattern if it pulled from a different direction, or adding to its pull to that of the current Moon if the two were lined up. This could cause much higher tides and widespread flooding, or far less tidal variation, with disastrous consequences for sealife.

Do we age differently in space?

Sort of – the lack of gravity on board orbiting spacecraft has some effects that are very like an accelerated form of ageing. For example, muscles begin to waste away with lack of exercise and the strength of your bones deteriorates in a very similar way to the effects of osteoporosis. Your heart also becomes less efficient because it doesn't have to pump blood against gravity. Fortunately, these effects are easily reversed on return to Earth. Ironically, though, travel at high speeds means that, through the strange effects of Einstein's theory of relativity, astronauts actually experience time passing slightly more slowly than those of us on Earth.

* * *



Do dead stars still shine in the sky?

Astronomers talk of a star 'shining' only when it is generating energy within itself by nuclear fusion, but stars continue to shine in the normal sense, pumping out huge amounts of light and other radiation, long after their fuel is exhausted and fusion has come to an end. White dwarf stars have superhot surfaces with temperatures of 100,000 degrees Celsius or more, and blaze with a searing mix of white light, ultraviolet light and X-rays – they're only faint because they're so tiny. They continue to glow for many millions of years as they gradually cool and fade.

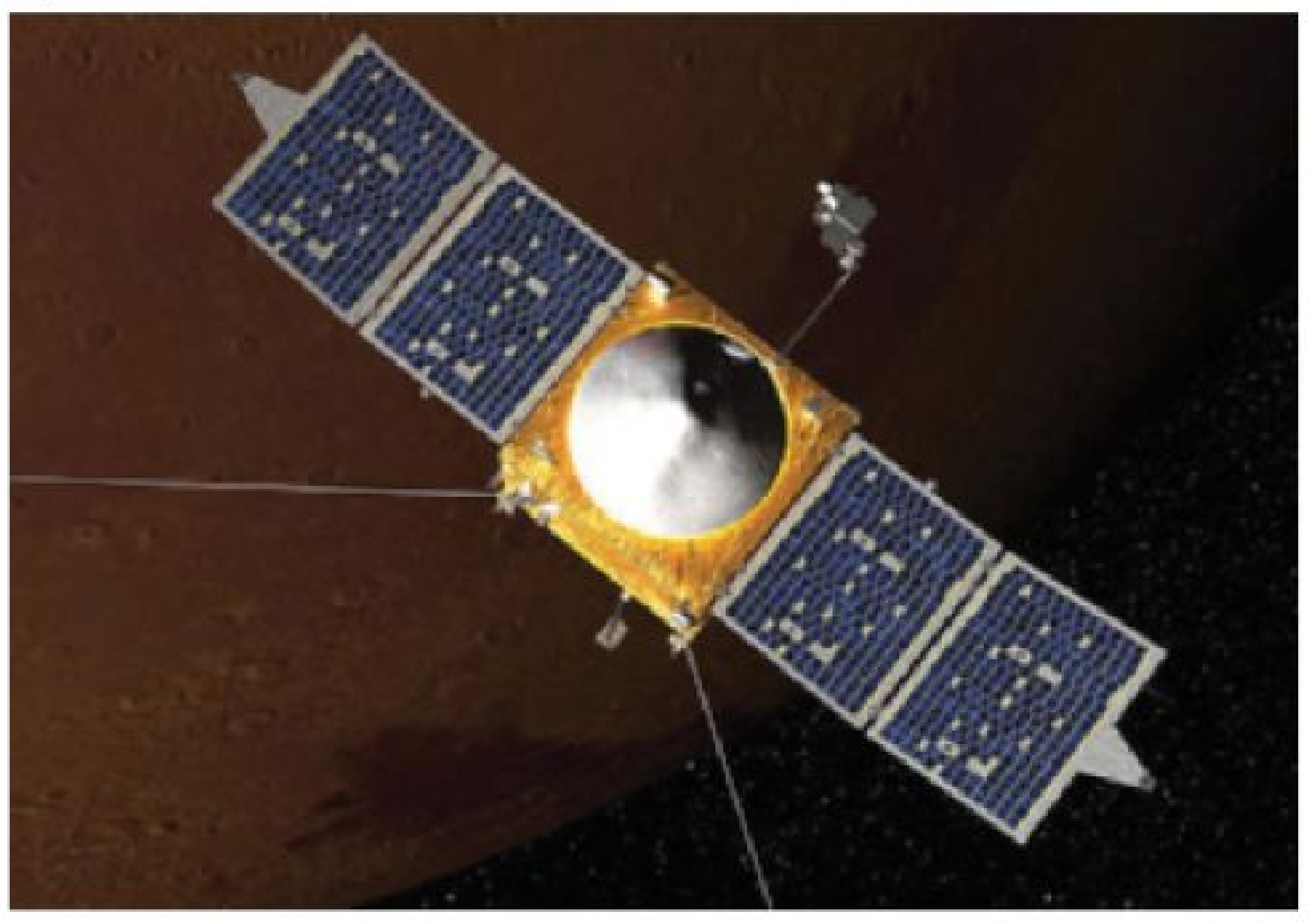
How do astronauts prepare for a spacewalk?

Preparing for a spacewalk takes about a day. Before astronauts step out, they need to go through a process called decompression. As there's no air pressure in space, spacesuits are pressurised at about a third of the air pressure inside the spacecraft. This both protects the astronauts and allows them to manoeuvre outside. Before they don the suit, the air pressure in the cabin is lowered and the oxygen levels slightly raised. If an astronaut just stepped outside, he could suffer serious illness or even death due to decompression sickness. Also called 'the bends', this occurs when nitrogen bubbles expand and quickly escape in the bloodstream due to a rapid decrease in air pressure. The decompression process allows the nitrogen to dissipate. A few hours before the spacewalk, the astronauts begin pre-breathing pure oxygen, which is what they'll breathe inside their spacesuits. They step into the airlock, put on their full suit, and the pressure inside slowly decreases until it's time to step out for their spacewalk.

Where is the best place in the world for stargazing?

You must find a balance between dark skies and accessibility. Mountaintop observatories like those on Mauna Kea, Hawaii, offer unparalleled views of the sky, but most will never visit. For amateur stargazers, the best locations are the Dark-Sky Parks and Reserves defined by the International Dark-Sky Association. The largest of these are the Death Valley National Park, California, USA and the Aoraki/Mount Cook park on New Zealand's South Island, but there are now three in the United Kingdom as well: Northumberland National Park in England, Brecon Beacons National Park in Wales and Galloway Forest Park in Scotland.

Why are we still sending probes to Mars?



Mars is perhaps the most interesting, and certainly the most Earth-like, world in the Solar System, and there's a huge amount still to find out about it. So far we've put fewer than a dozen space probes successfully into orbit around Mars, each carrying specialised instruments to teach us about new aspects of the surface, while the Curiosity rover was only the seventh safe landing on the Red Planet (and the fourth rover). Despite its more-or-less uniform colour, Mars is a hugely diverse world, with a variety of different environments and landscape features – we really have only scratched the surface, but as we do so, we're discovering evidence for an increasingly Earth-like past, raising major questions we still can't fully answer. How much water flowed on the surface? What happened to its atmosphere and oceans? These are mysteries that new craft like MAVEN and MOM are hoping to solve.

What would happen to your body if the force of gravity was doubled?

Doubling gravity would put your body under an immense amount of stress and could potentially be fatal if you were exposed to it for a protracted period of time. Firstly, your joints and skeleton would strain to support your increased weight. Then, your muscles would struggle with even the smallest of movements. But one of the most dangerous effects would be on your heart. Double gravity conditions would cause blood to pool in your extremities, making your heart have to work extra hard to keep the blood pumping around your body. Your blood pressure would have to double to overcome the increased gravity. Other processes inside the body might also be affected. Over time, very fit individuals might adapt and build stronger bones and muscles but any injury or illness would be incredibly difficult to recover from. Falls would be particularly dangerous in double gravity conditions. People who were less fit, overweight or affected by otherhealth conditions or illnesses would be unlikely to survive any long term exposure to double gravity conditions.

Environment

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Why do animals migrate?

Covering thousands of miles across land and sea, migrations are one of nature's true tests of endurance

For some species, a migration is a habitual journey every year, but for others it is the never-ending voyage of a lifetime. The key element that links every type of migration is the instinct to survive.

Animals will move location in order to position themselves in the best place for their needs. This could be a move with the seasons to escape the cold weather, like the swallows that leave UK shores for the balmier African climate each winter. Similarly, some animals will move where the food goes, or for other instincts such as to breed. Others will make the journey to safety to give birth, like humpback whales that migrate to calving grounds in the winter, and some migrate to raise young, escape overcrowding or to fulfil a biological need like moulting. Whatever the reason for such a journey, necessity is at the core.

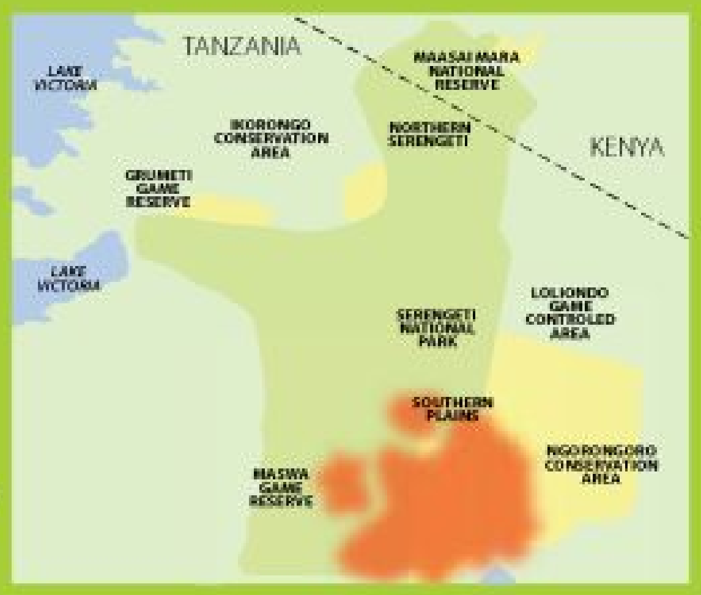
But how do they know where to go and when to leave? Each species has its own cues. For example, birds that leave the UK in winter can tell it's time to migrate when the days start to shorten and the nights get chillier. These seasonal cues also help them find their way. Visual clues, such as the position of the Sun, with other sensory clues like scent and sound of their destination alongside detection of Earth's magnetic field help all kinds of animals to navigate.

Animals can survive such journeys by fattening up, travelling in large groups and by hitching a lift on currents and winds. Migration is closely linked to seasonal changes and weather patterns. When things go wrong, this can affect the rest of the ecosystem. For example, due to climate change, some bird species are migrating earlier and departing later. This means that when they arrive too early there is not enough food to go around, and so their chicks suffer as a result. In turn, there are fewer of these birds for their predators to eat, and so on as the effect ripples through the ecosystem. ✿

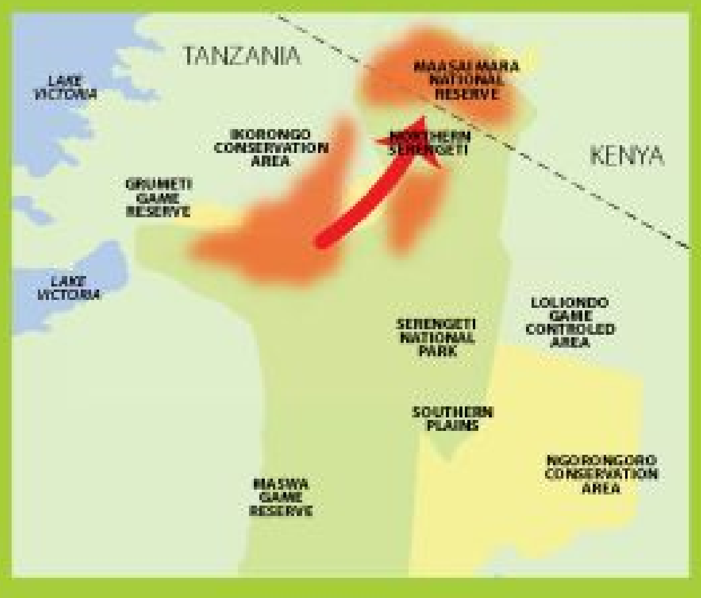
“Migration is closely linked to seasonal changes and weather patterns”

The Serengeti's great migration

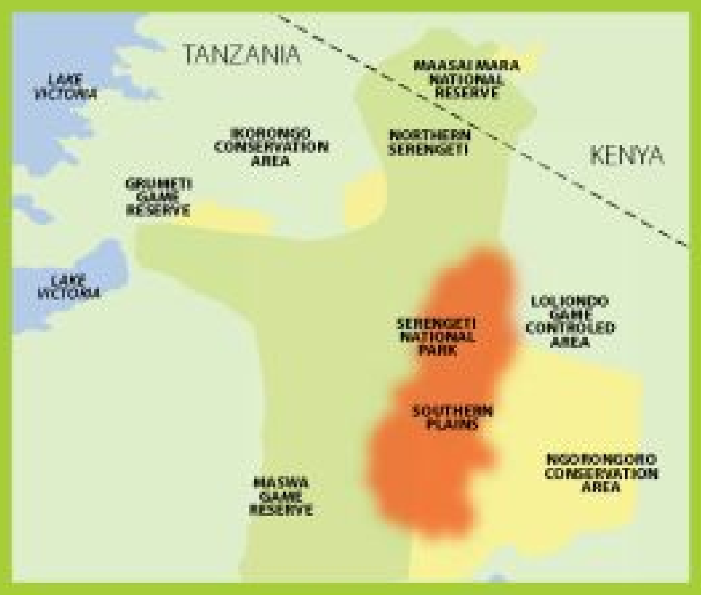
Year on year, huge herds of wildebeest, zebra, gazelle, eland and impala migrate around the Serengeti in search of fresh water sources and lush grazing areas



The herds spend January to March spread out and grazing the lush short-grass plains of the South Serengeti. The females calf in two to three weeks around February and March before starting their long journey north through Seronera as they head toward the Western Corridor in April and May.



June sees the vast herds split, as some cross the Grumeti River and move into the Grumeti Reserve, while others choose to head north. Over the summer months the herds gradually reunite in the northern part of the Serengeti National Park and spread out over the border into Kenya's Maasai Mara.



The wildebeest spend October in the far north of the Serengeti and into Maasai Mara before heading south, down the eastern side of the Serengeti National Park. As December arrives, the herds are just in time for the rains and graze on the lush southern plains once more.

The statistics…

Leatherback sea turtle migration

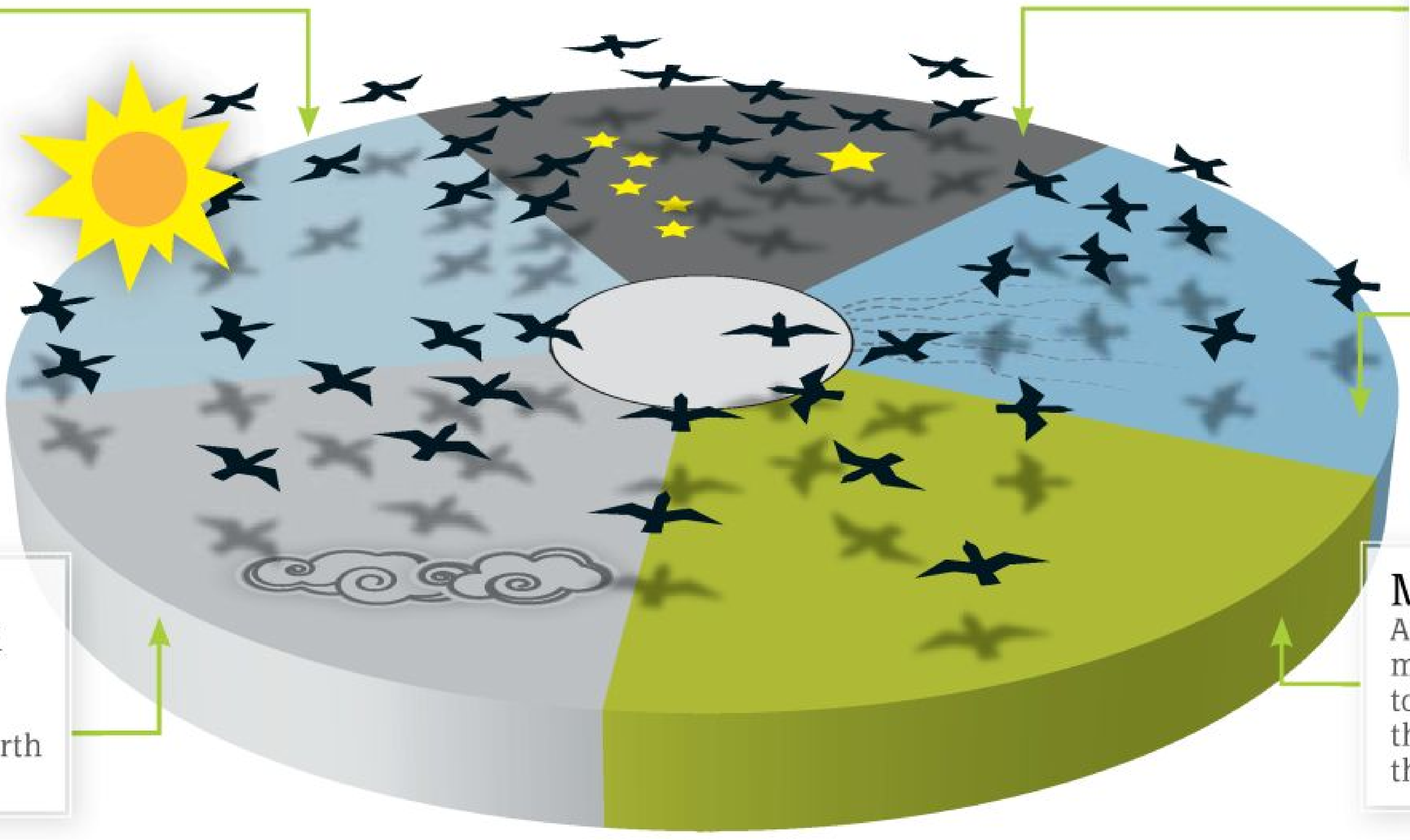
Distance: 16,000km (10,000mi)

The statistics…

2 million animals migrate across the Serengeti every year

How birds navigate

Birds sure don't need maps – they use incredible senses to find their way



Sun compass
Some birds, such as homing pigeons, use the Sun's position as a navigational cue. This is helped by their circadian rhythm (or 'internal clock') as the Sun tracks across the sky.

Star compass
Night migrations made by birds use the stars to find their way. This isn't an innate behaviour, so they birds must learn their north-south orientation by observing stars at a young age.

Odour map
A bird's sense of smell can put it on the right path. The scents of its home range can imprint a 'map' that can guide it back to the nest.

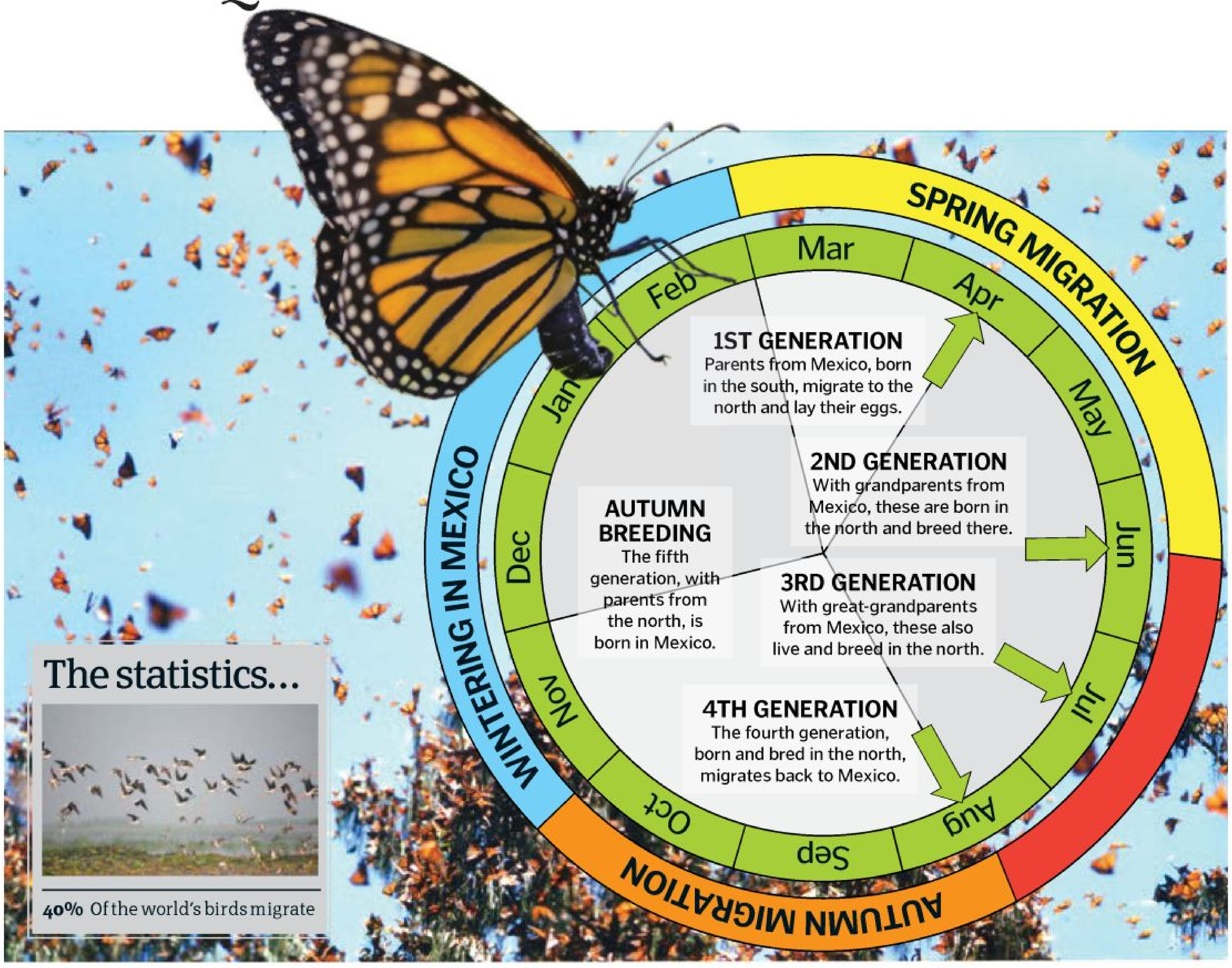
Magnetic map
Another theory is that many birds may rely on Earth's magnetic field to find their way. The strength of this field increases the further away the bird gets from the equator.

Magnetic compass
Migratory birds collect magnetic-field information through specialised receptors within their eyes. These receptors help them to distinguish north and south with no other visual clues.

Monarch butterfly

The monarch butterfly makes its home in the northern United States and Canada, but every year millions of them embark on a 4,828-kilometre (3,000-mile) journey south to the hills of central Mexico to avoid the harsh winter weather. Here they rest on tree branches in incredibly dense gatherings as they hibernate for four months.

What is incredible about this migration is that in summer, a monarch butterfly only lives up to six weeks. One generation migrates south, but it's that generation's grandchildren that migrate back north in the spring. Yet the butterflies always know where to go, sometimes even returning to the exact same trees their ancestors used.



1ST GENERATION Parents from Mexico, born in the south, migrate to the north and lay their eggs.

2ND GENERATION With grandparents from Mexico, these are born in the north and breed there.

3RD GENERATION With great-grandparents from Mexico, these also live and breed in the north.

4TH GENERATION The fourth generation, born and bred in the north, migrates back to Mexico.

AUTUMN BREEDING The fifth generation, with parents from the north, is born in Mexico.

The statistics…

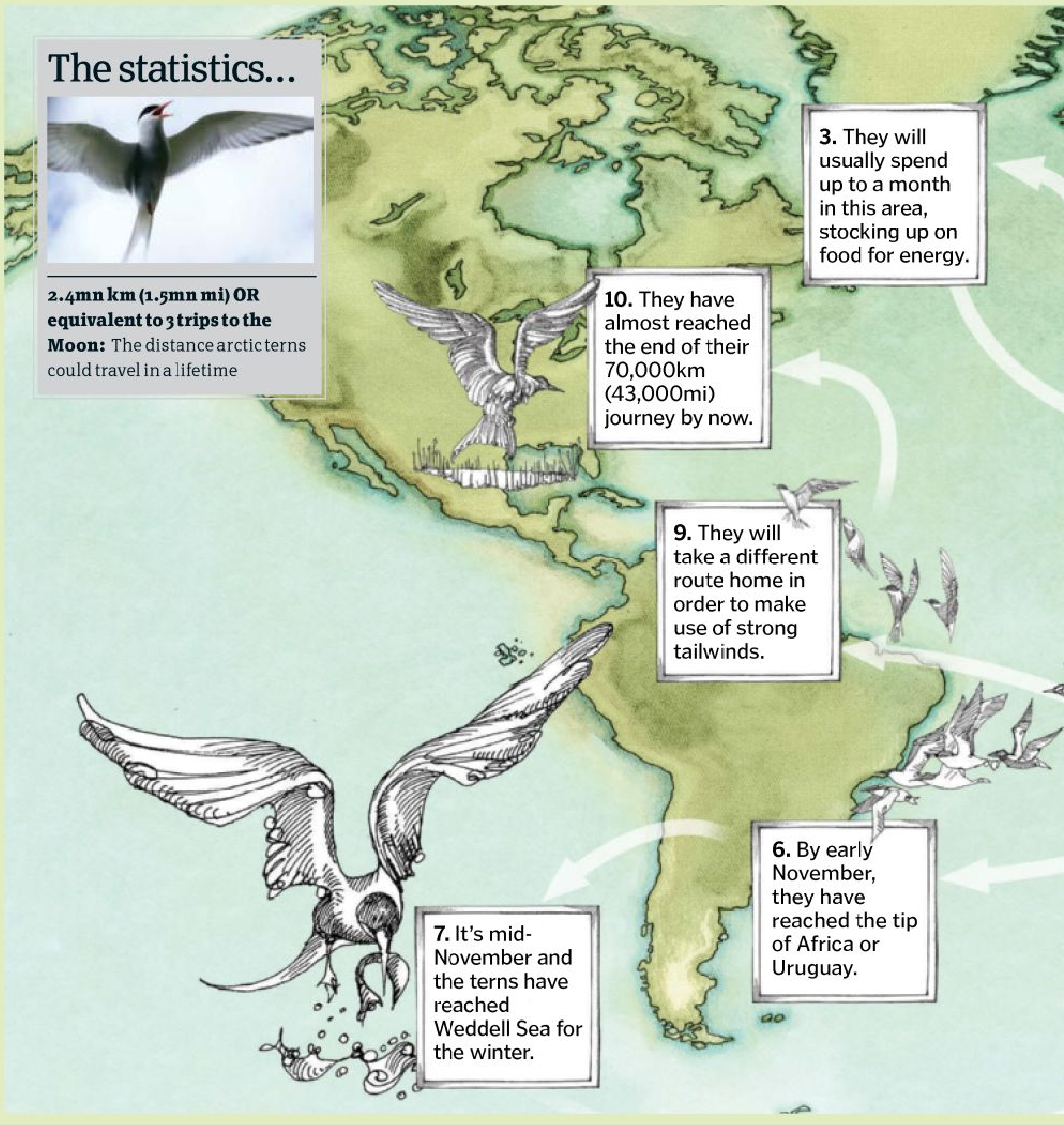
40% Of the world's birds migrate

Arctic tern

Every year, these little birds take to the wing to cover a mammoth distance, practically from pole to pole.

During the northern hemisphere summer, Arctic terns breed in colonies in Arctic and sub-Arctic regions of Europe, Asia and North America. 24-hour sunlight allows them to hunt and feed their chicks around the clock.

As the seasons begin to turn, these birds begin their flight south. They begin their 35,000-kilometre (21,750-mile) flight to the Southern Ocean where they will stay from November to March before returning to the Arctic to breed in the spring. This allows these birds access to 24-hour sunlight for eight months of the year!



The statistics…

2.4mn km (1.5mn mi) OR equivalent to 3 trips to the Moon: The distance arctic terns could travel in a lifetime

3. They will usually spend up to a month in this area, stocking up on food for energy.

10. They have almost reached the end of their 70,000km (43,000mi) journey by now.

9. They will take a different route home in order to make use of strong tailwinds.

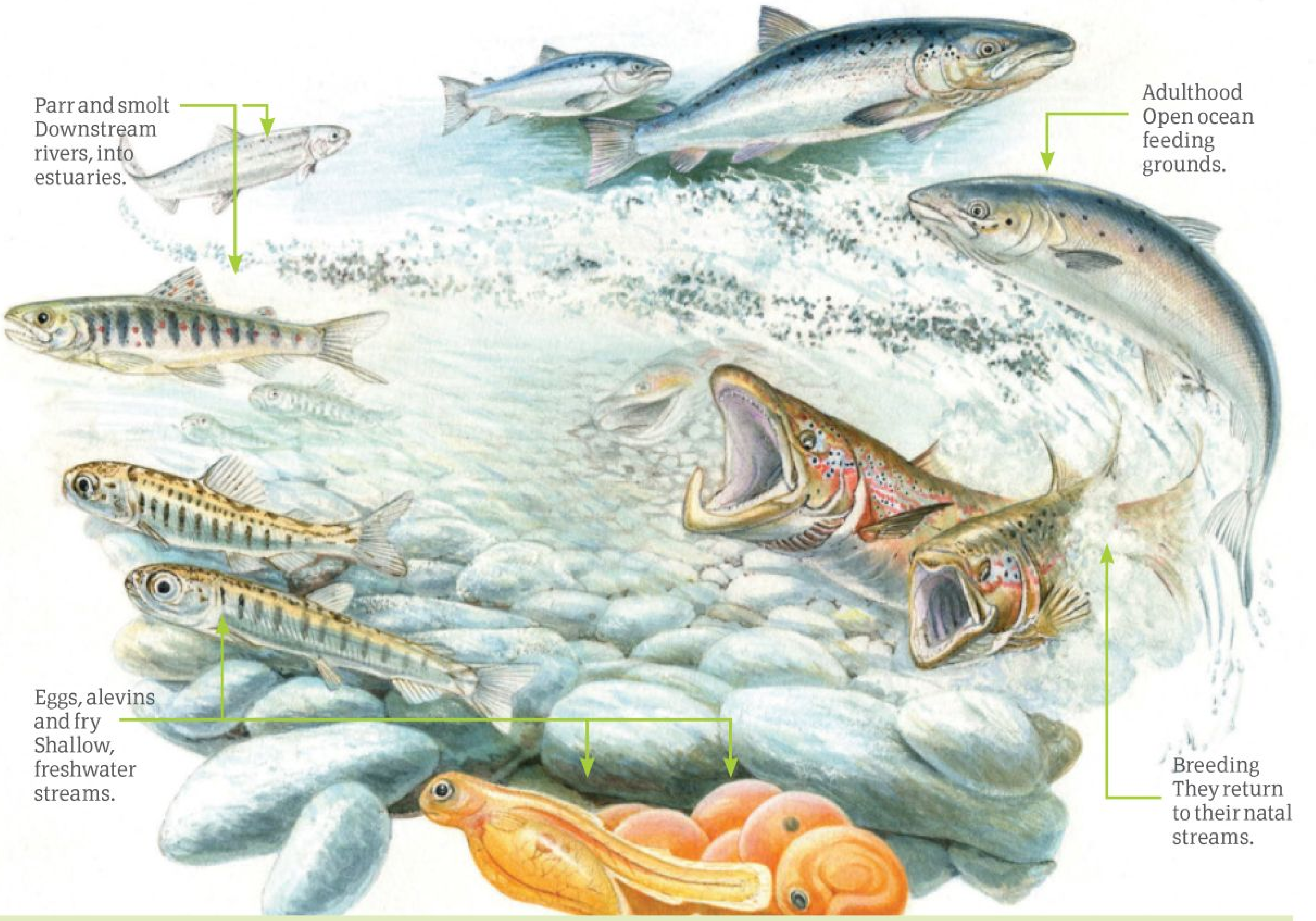
6. By early November, they have reached the tip of Africa or Uruguay.

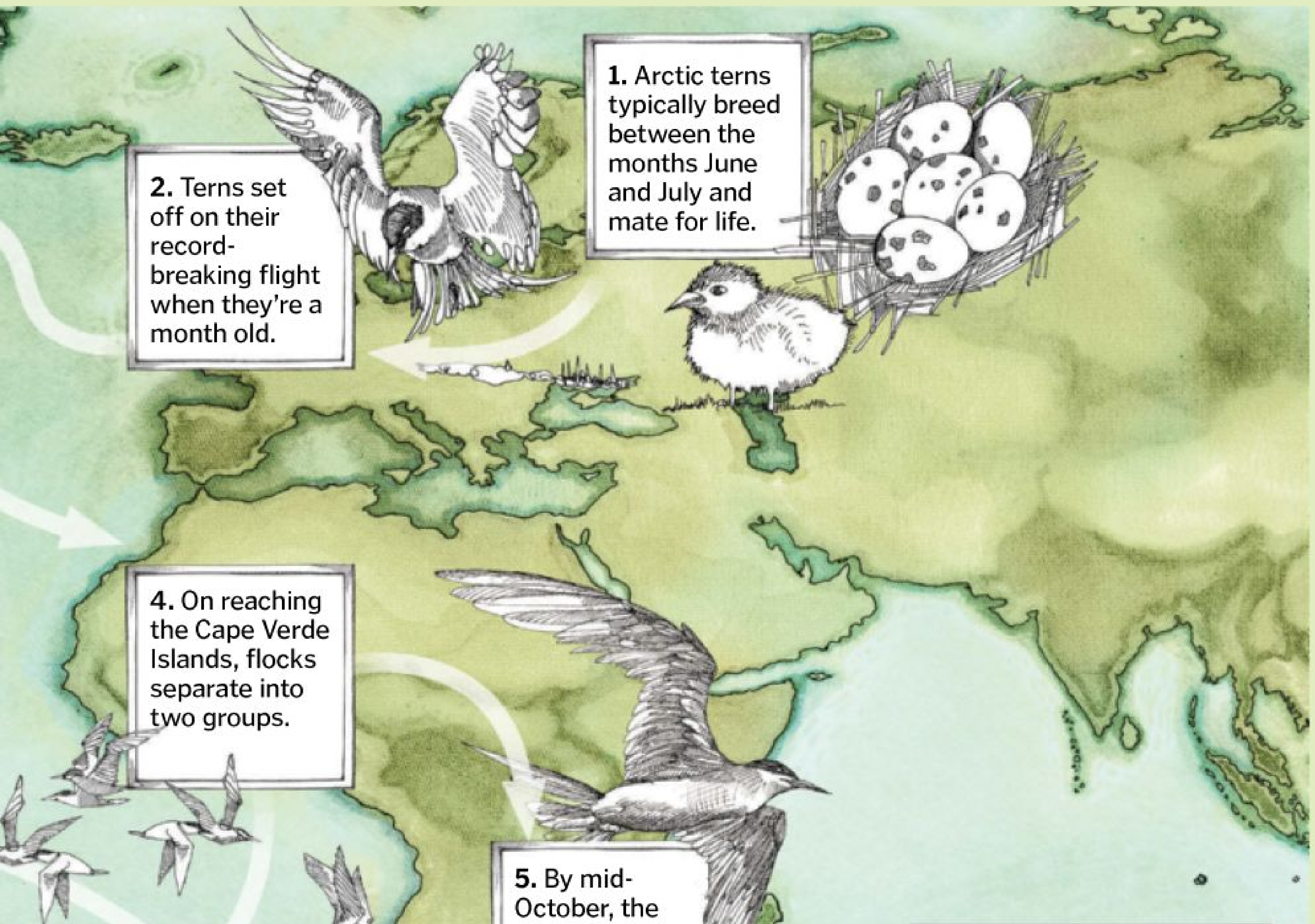
7. It's mid-November and the terns have reached Weddell Sea for the winter.

Salmon

The salmon's story begins with eggs laid in shallow freshwater streams, miles inland. As the young fish hatch and grow, they move downstream until they reach a river mouth. These hardy fish adapt from living in fresh water to living in salt water and then embark on an ocean-going journey as adult salmon to feed and grow at sea.

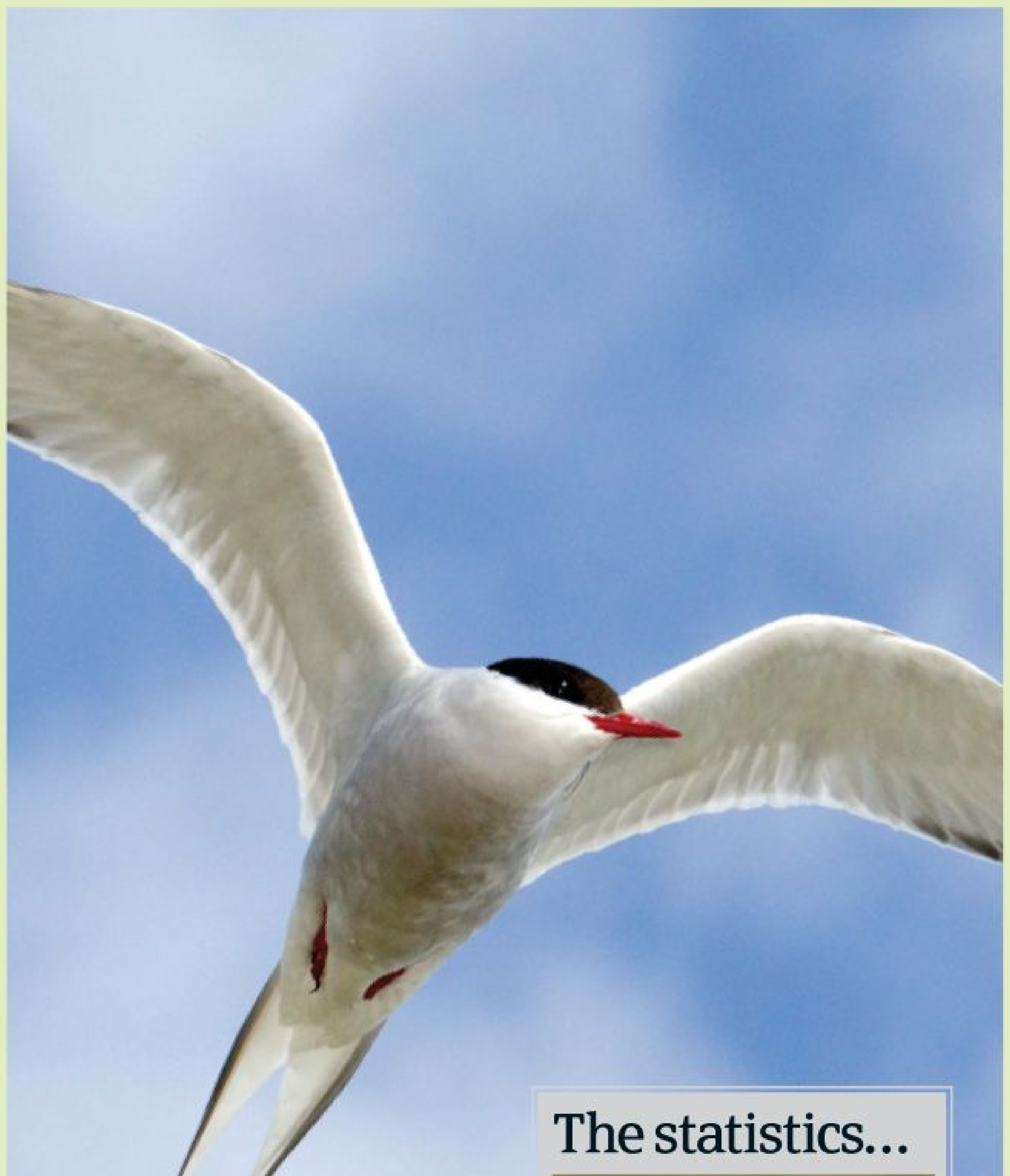
After a few years of fattening up, adult salmon make the staggering journey back to their home rivers to breed. They can home in on the exact location they were born using Earth's magnetic field, the imprint of their river's 'scent' and pheromones secreted into the water by other salmon.


Parr and smolt
Downstream rivers, into estuaries.
Adulthood
Open ocean feeding grounds.
Eggs, alevins and fry
Shallow, freshwater streams.
Breeding
They return to their natal streams.


1. Arctic terns typically breed between the months June and July and mate for life.
2. Terns set off on their record-breaking flight when they're a month old.
4. On reaching the Cape Verde Islands, flocks separate into two groups.
5. By mid-October, the terns cross the equator, eating and sleeping on the wing.
8. In April, they prepare for the flight home to their breeding grounds.

The statistics…

95-160km (60-100mi): The distance emperor penguins migrate over ice



The statistics…

11,500km (7,150mi): The Bar-tailed godwit's longest non-stop migration

© Thinkstock; Andreas Trepte; NPS Photo/Ken Conger; Albert Herring; Faisal Akram; Michael L. Baird; OddurBen; Ron Knight

Can caves have climates?

Explore one of China's most stunning cave systems to learn why it has developed its own microclimate

Cut off from the Sun, rain and wind that we experience on the surface, you might assume meteorological conditions in caves never change. However,the reality is that their climates do vary significantly – not only from location to location, but within individual caves over time. Indeed, some examples, like the Er Wang Dong cave system in Chongqing Province, China (main picture), even host their own weather. Ultimately this is because very few caves are 100 per cent cut off from their surroundings.

In the case of Er Wang Dong, it all comes down to an imbalance in the local topology. There are several tunnels around the cave system's perimeter where wind can blow in. Once trapped underground air from outside gains moisture, pooling into huge chambers like Cloud Ladder Hall – the second-biggest natural cavern in the world with a volume of 6 million cubic metres (211.9 million cubic feet). Once in an open chamber this humid air rises.

While there are numerous entrances into this subterranean complex, exits are few and far between. In Cloud Ladder Hall's case, it's a hole in the roof some 250 metres (820 feet) above the floor, leading to a bottleneck effect. As the damp air hits a cooler band near the exit, tiny water droplets condense out to create wispy mist and fog. In other chambers plants and underground waterways can also contribute to underground weather.

Even caves without any direct contact with the outside world can still experience climatic variations, as they are subject to fluctuations in atmospheric pressure and geothermal activity, where the heat from Earth's core emanates through the rocky floor. However, in such caves, changes are more evenly distributed so take place over longer time frames. ✱

Here, fog clouds can be seen in the deep sinkhole at the entrance of the caves while the Sun shines above it

Sizing up Cloud Ladder Hall

© Robbie Shone

What are Von Kármán vortices?

The science behind these mind-boggling, swirling cloud formations is revealed by Von Kármán

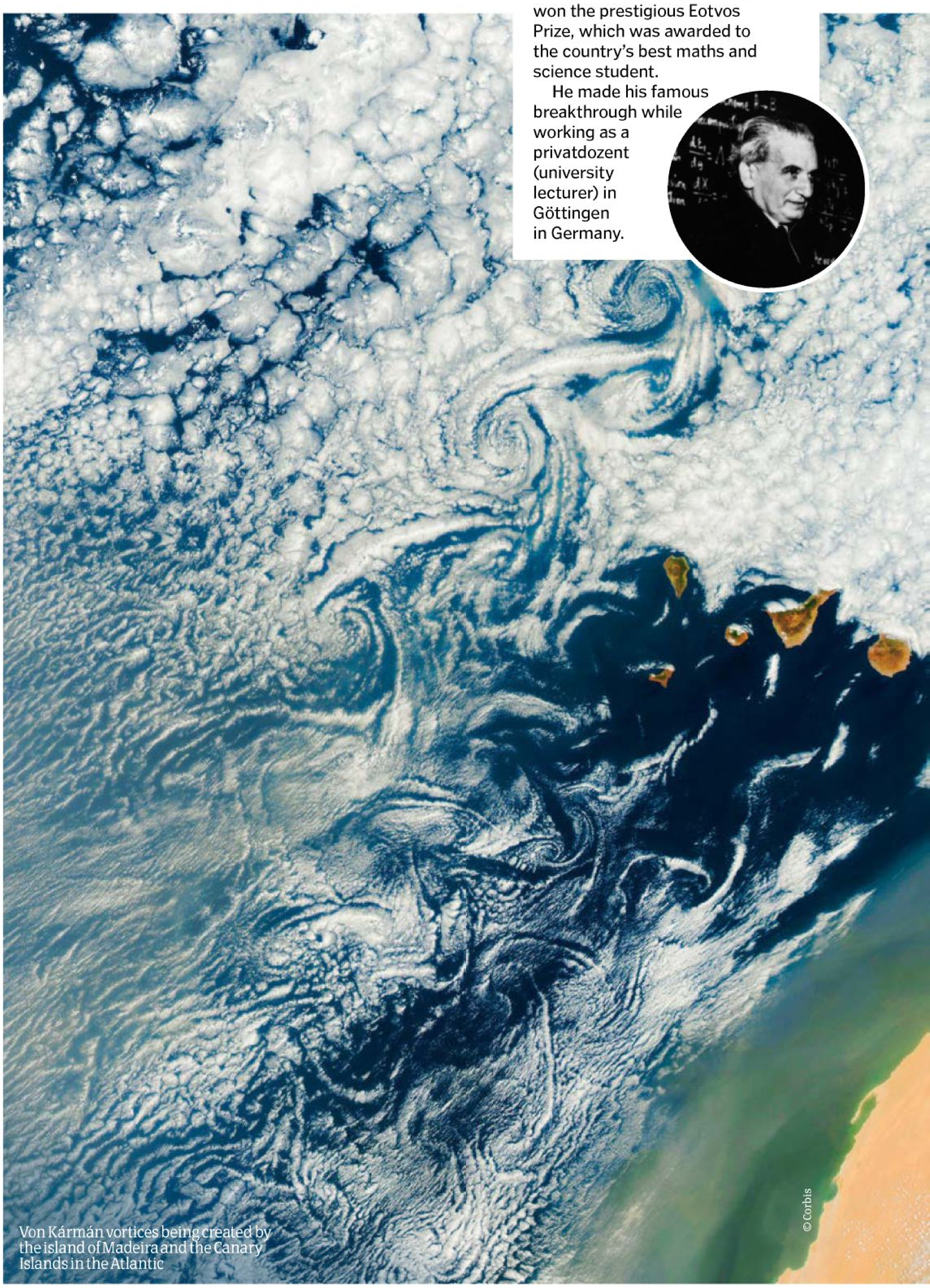
The area of fluid dynamics is one in which scientists are still getting to grips with, but back in 1911, a Hungarian called Theodore von Kármán worked with a flow tank to demonstrate the effect that a stationary body can have on the flow of a fluid passing over and around it.

As the fluid flow, such as a cloud formation, is disrupted by a cylinder – in nature this is generally an island or group of islands – the fluid is forced to either side of the barrier. The fluid flows around the obstruction, forming a boundary layer close to the object, which hugs it closely. As the flow continues, the boundary layer becomes a shear layer, which continues to move away from the barrier. If there is any kind of pressure imbalance coming from either side of the barrier, the side with greater pressure forces the fluid flow upward, separating it from the main flow and causing a swirling eddy. Having broken off one stream, the cloud then folds back on itself, causing the side with more pressure to be cut off and swirl away in the opposite rotational direction, creating a vortex.

As the flow continues, the alternation of pressure imbalances continues, generating what is known as a 'street' of repeated vortices swirling in different directions (see image, right), pushed along by the fluid flow.

However, not all fluids that meet a barrier result in a Von Kármán vortex street. The pressure imbalance is measured by using Reynolds numbers, which represent the ratio of moving forces to stationary forces in a fluid flow. The higher the Reynolds number, the more likely a fluid flow will be turbulent rather than laminar (ie a smooth flow).

This phenomenon discovered by Von Kármán is most commonly seen in clouds as they are pushed along by the air current and disturbed by high-above-sea-level islands and mountains, but they can also be observed in the ocean and on ice.



Von Kármán vortices being created by the island of Madeira and the Canary Islands in the Atlantic

© Corbis

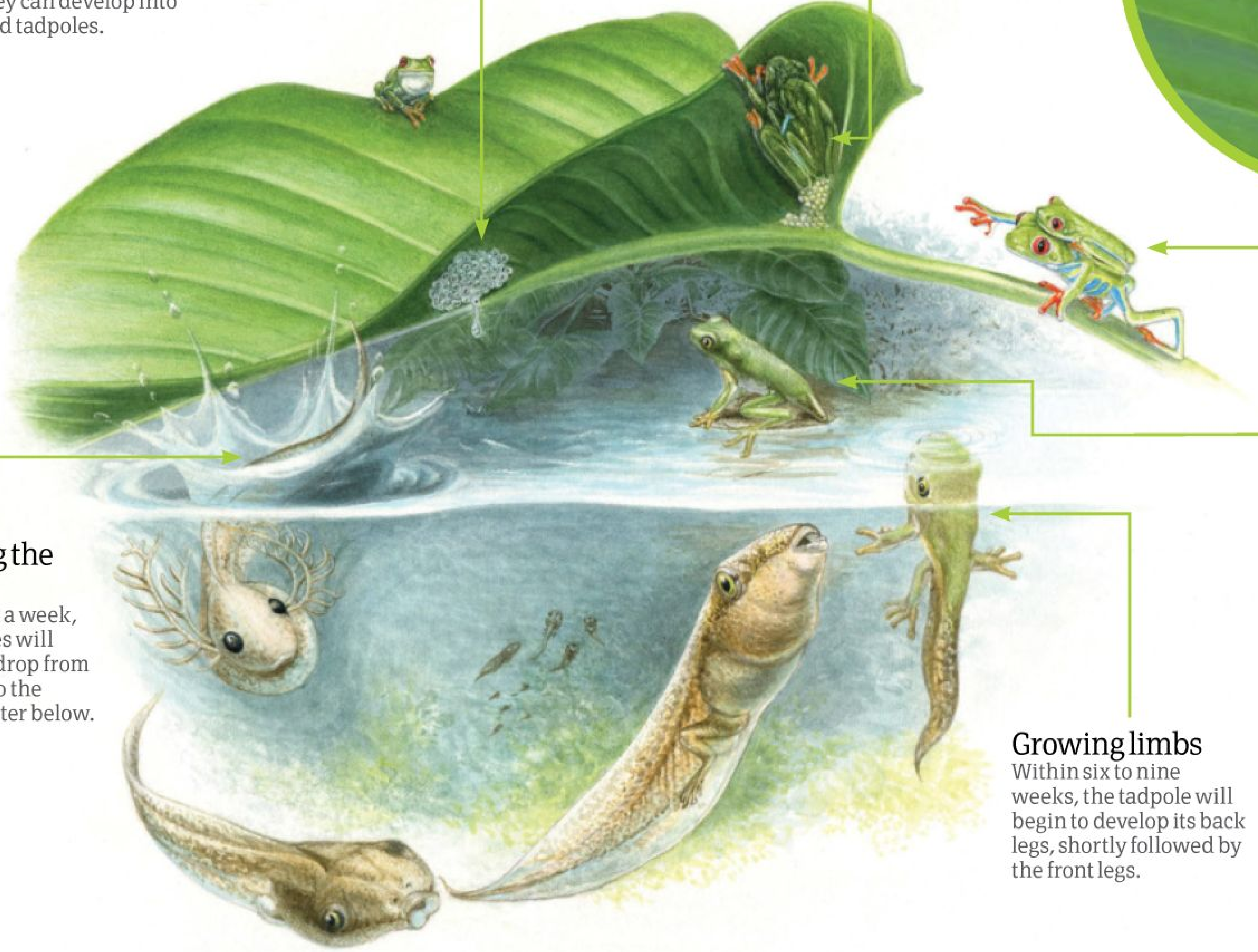
The man behind the mystery

Theodore von Kármán was born in Budapest, Hungary, on 11 May 1881. His father, a philosophy and education professor, made him practise subjects such as geography and history. However, Von Kármán's natural maths ability shone through and he won the prestigious Eotvos Prize, which was awarded to the country's best maths and science student.

He made his famous breakthrough while working as a privatdozent (university lecturer) in Göttingen in Germany.

How do tree frogs age?

Discover how the elusive red-eyed tree frog begins its life in water before moving to land



Developing tadpoles
A surrounding jelly-like substance keeps the eggs in place so they can develop into fully formed tadpoles.

Fertilising the eggs
The female tree frog will then deposit 30-50 eggs onto the underside of a leaf that hangs directly above water. The male will then fertilise the eggs.

Finding a mate
Between October and March, the male red-eyed tree frog will attract a female by croaking. It will then latch onto her back.

Entering the water
After about a week, the tadpoles will hatch and drop from the leaf into the waiting water below.

Adult life
Within three months, the young red-eyed tree frog is ready to move from the water into the nearby trees and begin the cycle anew.

Growing limbs
Within six to nine weeks, the tadpole will begin to develop its back legs, shortly followed by the front legs.

Do eels shock prey?

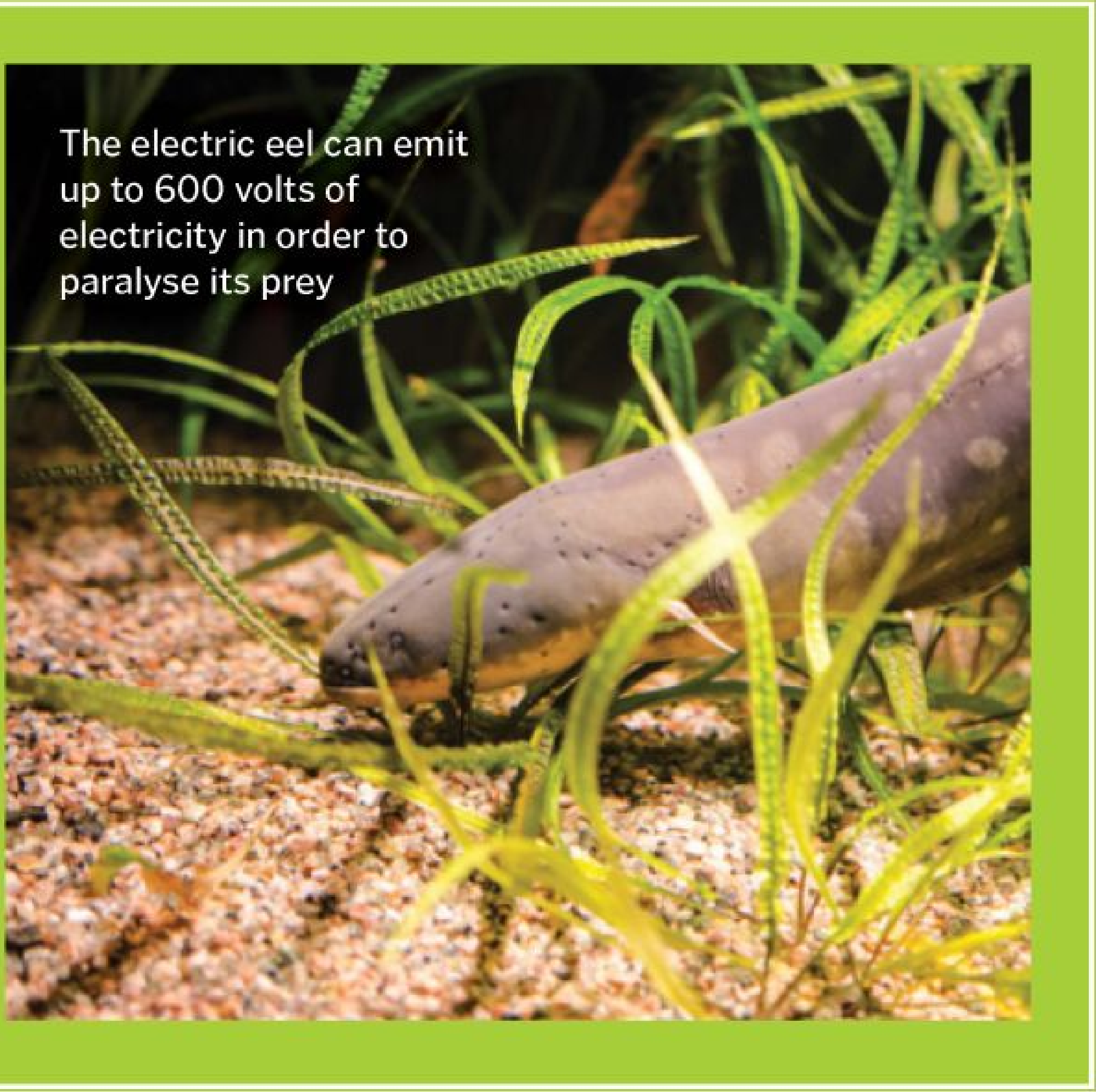
Discover how electric eels shock unaware prey into submission

The electric eel is a formidable freshwater predator that has the ability to emit a powerful voltage of electricity underwater. This unique shock tactic is used in order to immobilise passing prey in murky surroundings.

Releasing pulses of electricity actually makes hunting fish much easier for the eel. Put simply, the sharp electric bursts have a direct effect on a unsuspecting fish's muscles, often causing them to twitch or convulse, which in turn gives away their position to the predator.

Electric eels are capable of producing such an incredible shock as they have electric organs, which can store power like a battery. Once the eel plans to attack, thousands of specialised electrocyte cells within the organs will discharge, enabling the eel to emit a powerful burst of electricity up to 600 volts!

Due to their poor eyesight, electric eels will use the same technique to ward off predators and navigate in their gloomy freshwater surroundings too, but will emit a lower charge when doing so. ✽



The electric eel can emit up to 600 volts of electricity in order to paralyse its prey

©Thinkstock; Catarii / Dreamstime

What is a geyser?

Discover the underground secrets of Earth's geothermal activity

A geyser is a rare hot spring that erupts in a violent display of water and steam. The key to this amazing phenomenon is a mixture of heat and constriction.

The discharge from a geyser is essentially geothermal heat escaping from the ground. Rather then having a constant flow of water like a conventional hot spring, they have a complex 'plumbing' system that periodically releases the steam. Constrictions near the surface are created by the dissolution of silicon dioxide (silica) from the igneous rock rhyolite by hot water. This creates sinter, which forms the characteristic cone of a geyser.

Water from rain and snow make their way into the hot porous rock created from a deep underground magma chamber. This superheats and evaporates the water to create steam, which bursts out into the air as more and more pressure is added onto the near-surface constrictions. The steam takes up to 1,600 times more space than the original volume of water and is over 100 degrees Celsius (212 degrees Fahrenheit). On some geysers, the pressure can be diverted through various side channels, as well as the major release outlet. There are two types of geyser: cone and fountain. The former type is named due to the shape of the formation of the spout hole while the latter type is a flat pool of water.

Human activity can affect geysers. In the past there used to be two large geyser fields at Beowawe and Steamboat Springs in Nevada but they were destroyed by the construction of geothermal power plants, which took away the heat needed to power them. A similar occurrence happened in New Zealand when a hydroelectric dam flooded the geyser area.

Yellowstone National Park in Wyoming, USA, has over 500 geysers, more than any other area in the world. This includes the famous Old Faithful, which erupts on an average of every 90 minutes, and the world's largest, Steamboat Geyser, that blasts water up to 90 metres (300 feet) into the air! Don't make a journey especially to see it, though; it has had less than ten major eruptions in the last 20 years! Following an eruption, water gradually flows back into the hole on the surface and the process starts all over again.

Geyser wannabes

Hot spring Japanese macaques enjoying a nice, hot spring bath.

Fumarole: Fumaroles on the Fourpeaked Glacier in Alaska.

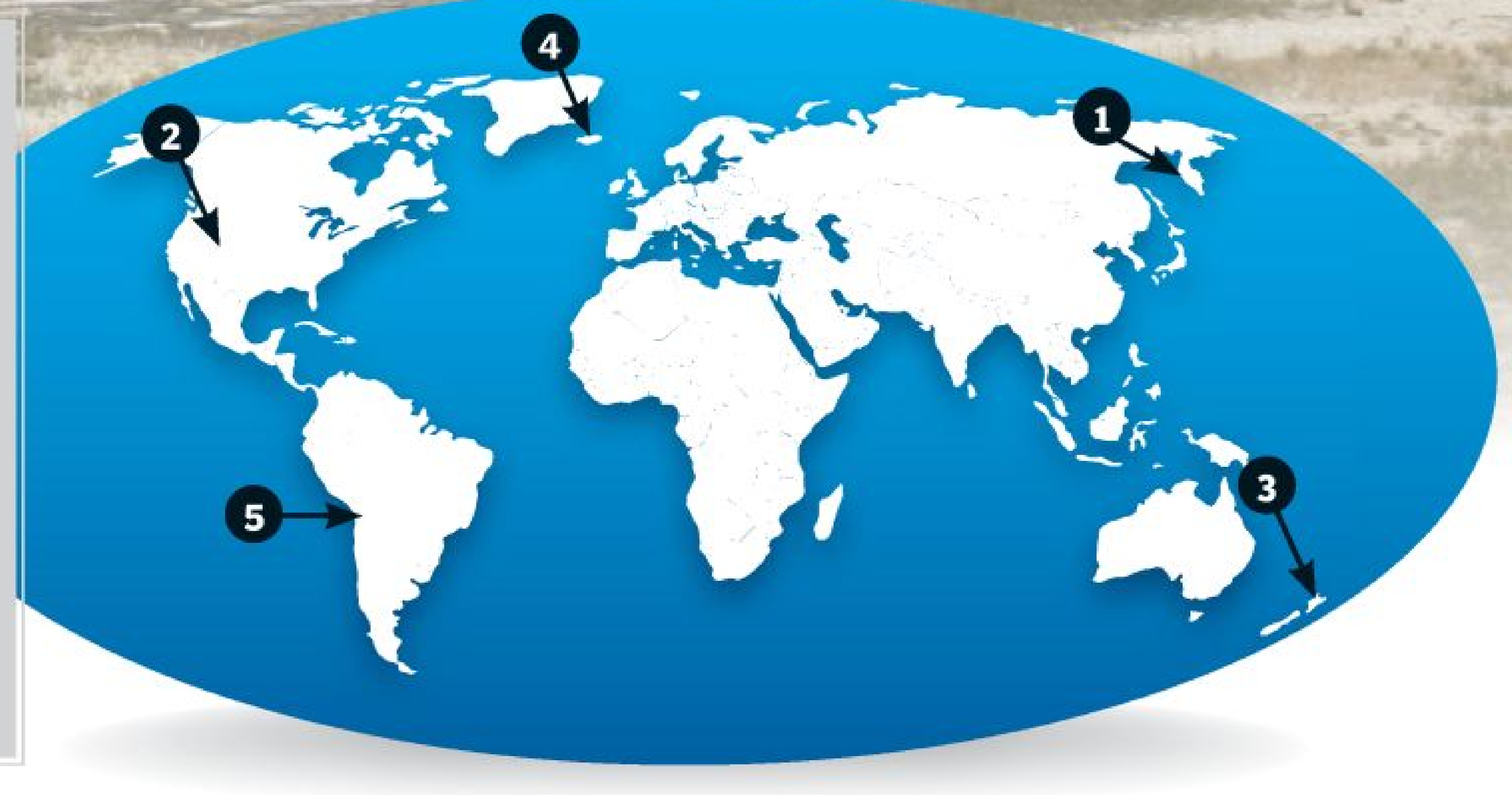
Mudpot: A mudpot in Yellowstone National Park.

Geyser hotspots

On the map

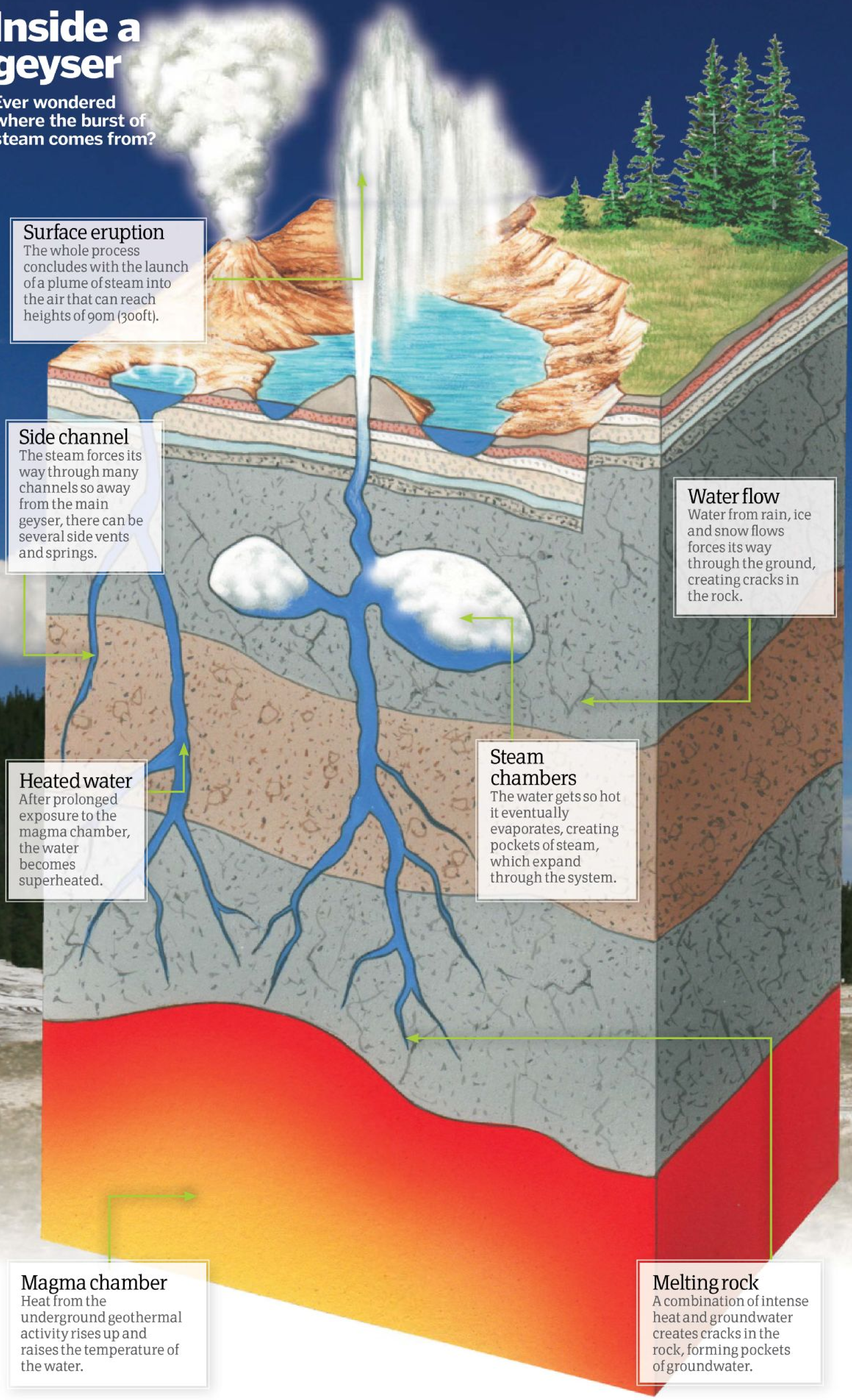
Geyser centres around the globe

1 Valley of Geysers, Russia
2 Yellowstone National Park, USA
3 Taupo Volcanic Zone, New Zealand
4 Haukadalur, Iceland
5 El Tatio, Chile



Inside a geyser

Ever wondered where the burst of steam comes from?



Surface eruption
The whole process concludes with the launch of a plume of steam into the air that can reach heights of 90m (300ft).

Side channel
The steam forces its way through many channels so away from the main geyser, there can be several side vents and springs.

Water flow
Water from rain, ice and snow flows forces its way through the ground, creating cracks in the rock.

Steam chambers
The water gets so hot it eventually evaporates, creating pockets of steam, which expand through the system.

Heated water
After prolonged exposure to the magma chamber, the water becomes superheated.

Magma chamber
Heat from the underground geothermal activity rises up and raises the temperature of the water.

Melting rock
A combination of intense heat and groundwater creates cracks in the rock, forming pockets of groundwater.

Space geysers

Not just limited to Earth, extraterrestrial geysers have also been witnessed. Io, a moon of Jupiter, has been shown to have volcanic features including surface vents that launch sulphur dioxide into the atmosphere. The largest two are known as Prometheus and Pele, which can discharge the sulphur 300 kilometres (186 miles) into the air! Cold geysers known as cryovolcanoes have also been found on the Saturnine moon of Enceladus. These are similar to the geysers on Earth and release water vapour. Jokingly nicknamed 'Cold Faithful', these underground springs go a long way to proving the theory that a lake of liquid water lies under Enceladus' surface. Geothermal activity is also common on Mars with carbon dioxide emissions frequent in the Martian spring when a warmer temperature allows the gas to discharge.

ABOVE Prometheus can be seen right in the centre of the image while the gas on the top of Io is discharge from another geyser

© Galileo Project, JPL, NASA; Dreamstime

Fairy rings or frightening fungus?

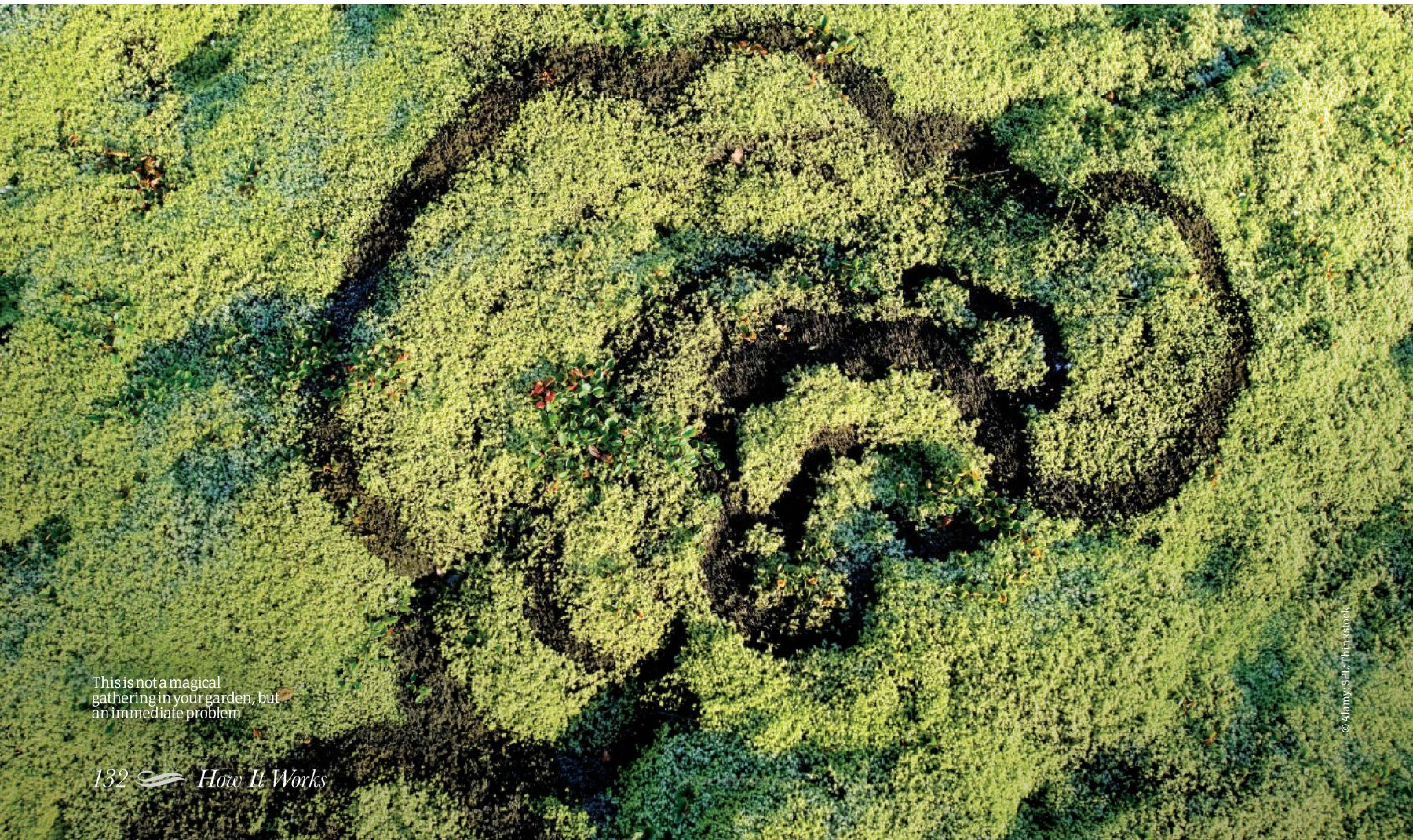
It may sound otherworldly but this garden phenomenon is very real

Every now and again, a perfectly normal lawn or patch of grass will begin to grow a strange circle of toadstools. Unfortunately, this is not a community of fairies setting up camp in your back garden, but an outbreak of the fungus Marasmius oreades.

The Marasmius oreades fungus is attached to the roots of turf, having been carried by the wind from other toadstools. They form rings because the mycelium – the tubes that form the underground body of a fungus – grows in an outward direction. After the fungus has spread, the centre of the mycelium dies off, so by the time they are ready to grow above ground, the remaining toadstoolswill have formed a ring shape on the surface.

They are very unpopular among gardeners because, once the fungus has latched onto a grass root, it usually means the grass will die, forming an ugly patch of dead grass. Removing the toadstools will do little to stop the problem as the fungus has already taken hold. The best way to combat fairy rings is to remove the turf and soil and replace it with new turf and soil.

Alternatively, you could try spiking the ground and watering the area heavily. The fungus will have dried out the lawn and made it water repellent, so heavy watering will give the grass enough water to grow and resist the drying effect of the fungus. Fairy rings tend to occur around late summer and early autumn, so if you are a gardener or fairy spotter, this is the time to keep your eyes peeled.

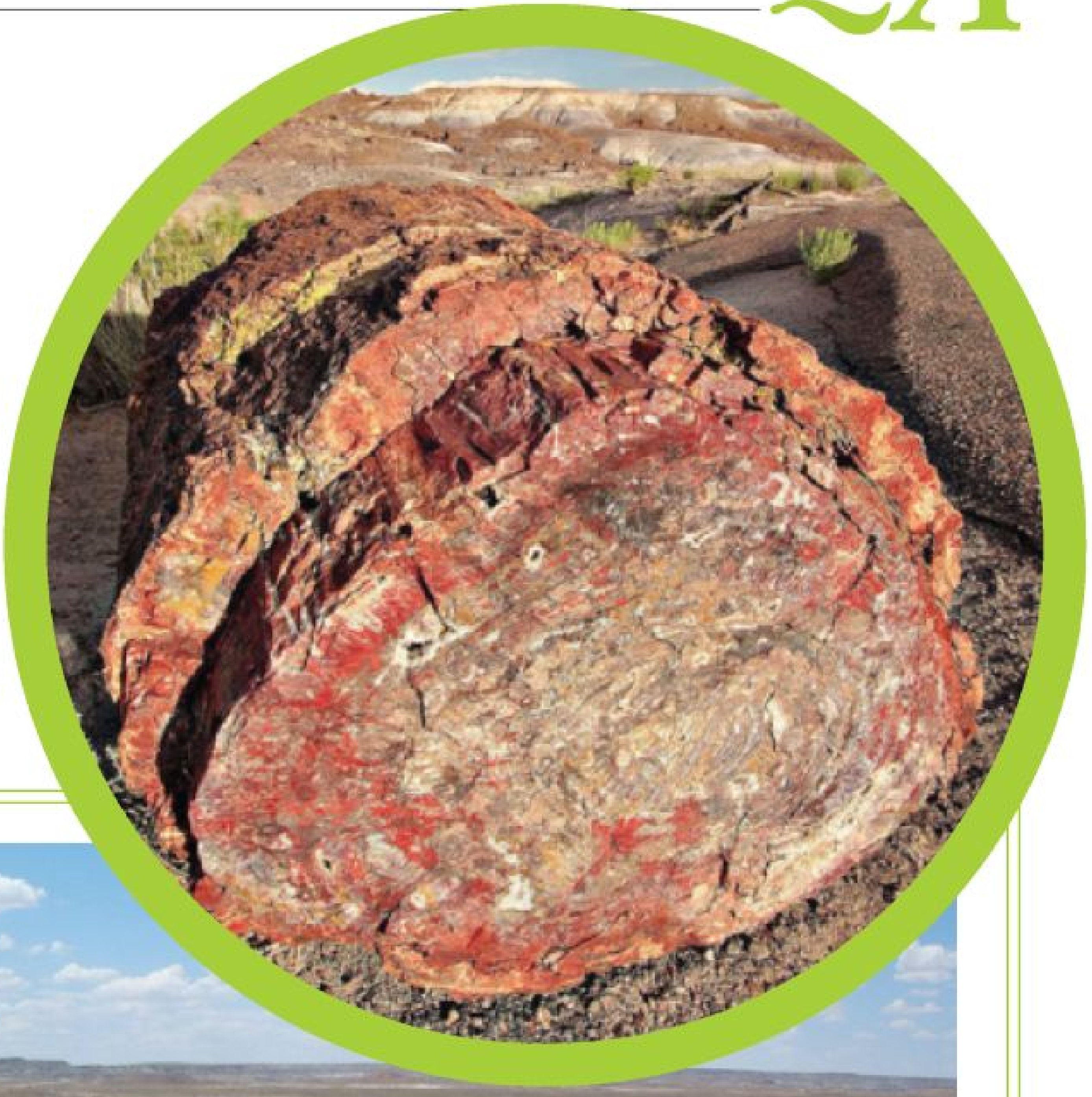


This is not a magical gathering in your garden, but an immediate problem

© Alamy; SPL; Thinkstock

What is a petrified forest?

Perfectly preserved 225-million-year-old trees



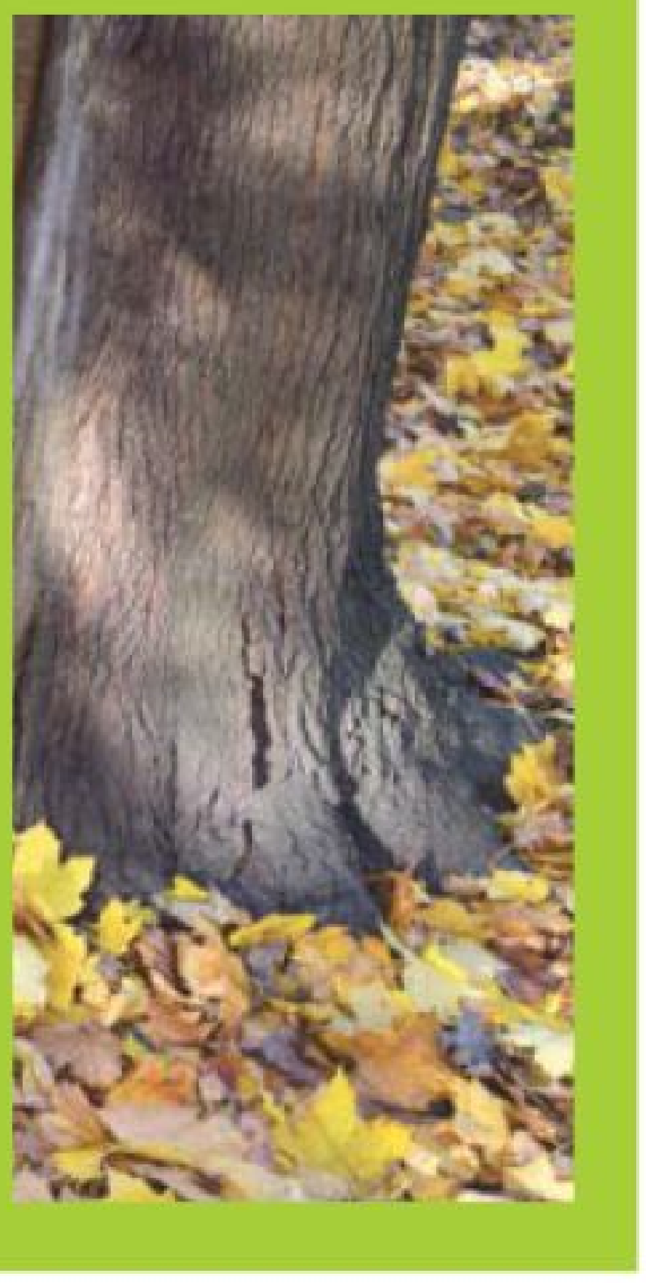
All over the world you can find strange-looking slabs of wood, strewn across a barren landscape. However, these haven't actually been wooden for millions of years.

Around 225 million years ago, prehistoric trees fell into rivers, where they were quickly covered with a layer of sediment, silt and mud. This rapidly formed a tight wrap around the trunk, cutting off any oxygen that would have rotted the wood. Over time, minerals were absorbed into the wood, including silica. This material is known for its crystallising properties and as the log slowly rotted away over a period of many centuries, the silica replaced it, forming stunning crystal representations of the original material's shape and turning the wooden logs into quartz slabs.

As the floods washed or evaporated away, they left these quartz slabs scattered around the plains. Wind and sand erosion continued to batter these slabs until the last few pieces of organic material was stripped away, leaving stunning quartz blocks dotted around barren, arid landscapes around the world.

Petrified wood tends to be found in areas near volcanoes. This is because the silica, which is key to the production of the stunning crystals, usually comes from ash spewed out by an erupting volcano. Most petrified forests are protected areas, so you are allowed to go and view these incredible natural phenomena, but unfortunately you can't take any of it home for your mantelpiece. ✲

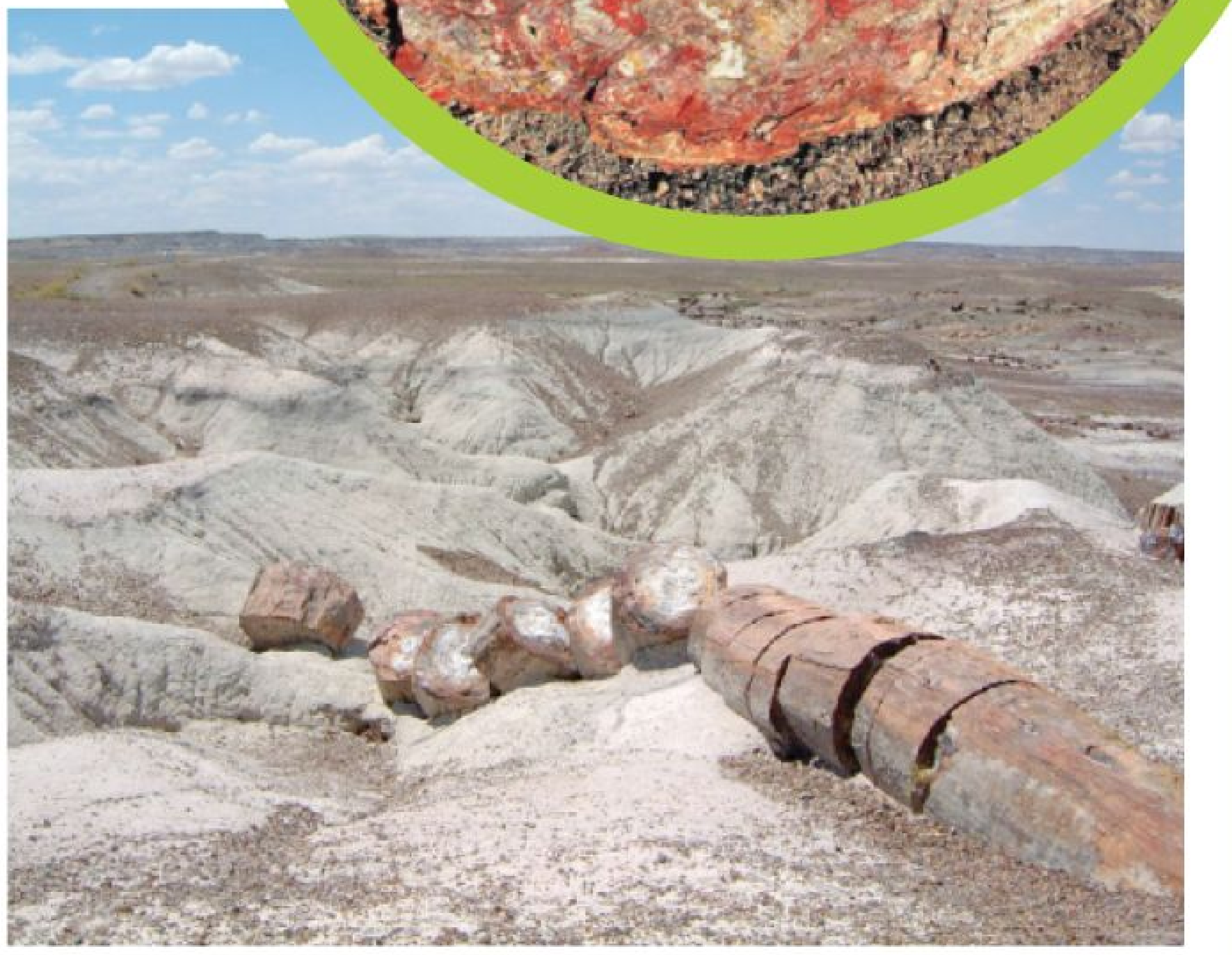
Why do plants rot?

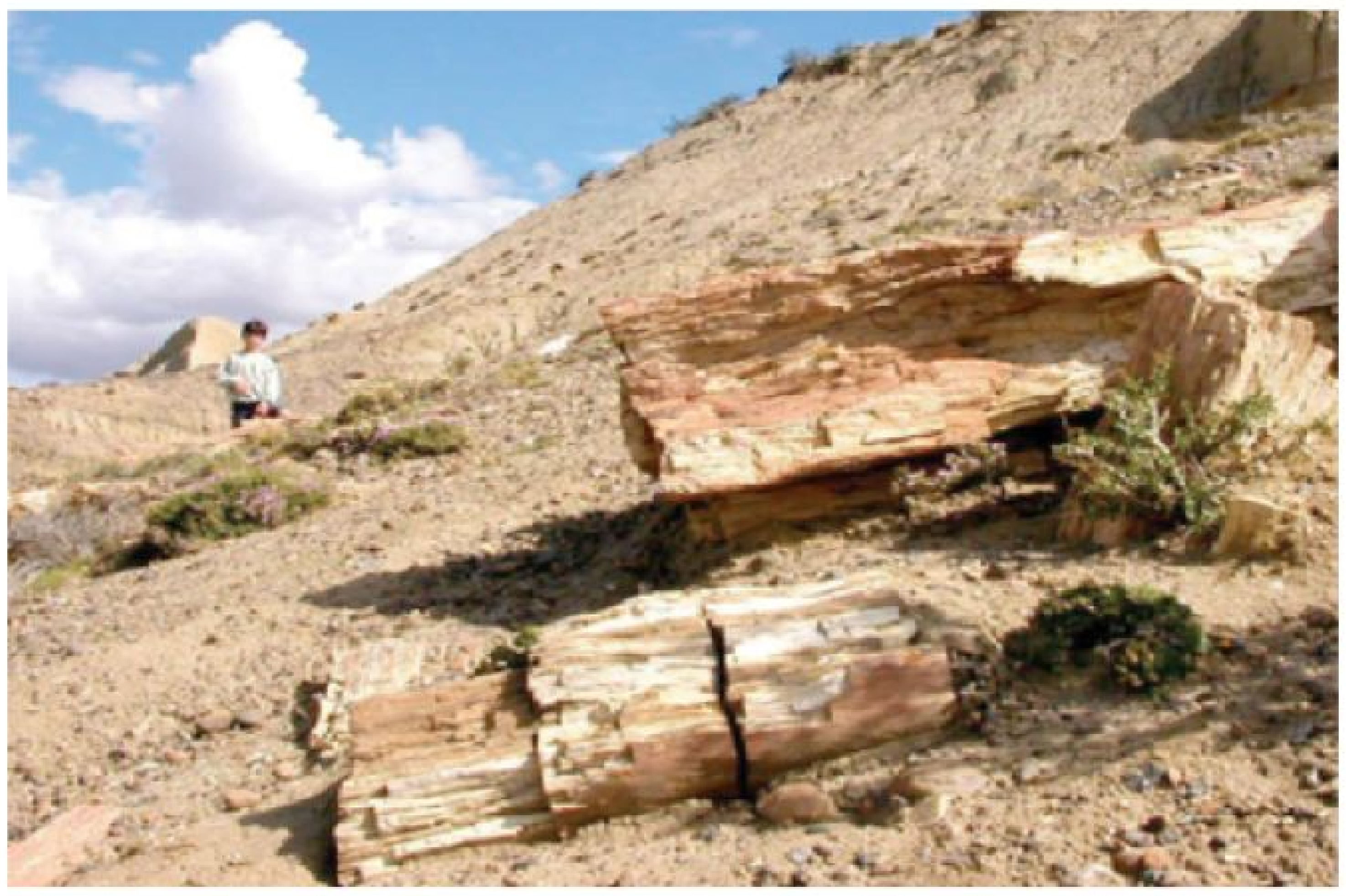


Once a plant dies, it will start to rot (decompose). They decay because microorganisms release enzymes that break down compounds for digestion. Bacteria and fungi – the main decomposers – depend on moisture and oxygen for their respiration. When both are absent from the process, the microorganisms work much slower and, in the case of petrified wood, rotting takes up to millions of years.

Notable petrified forests

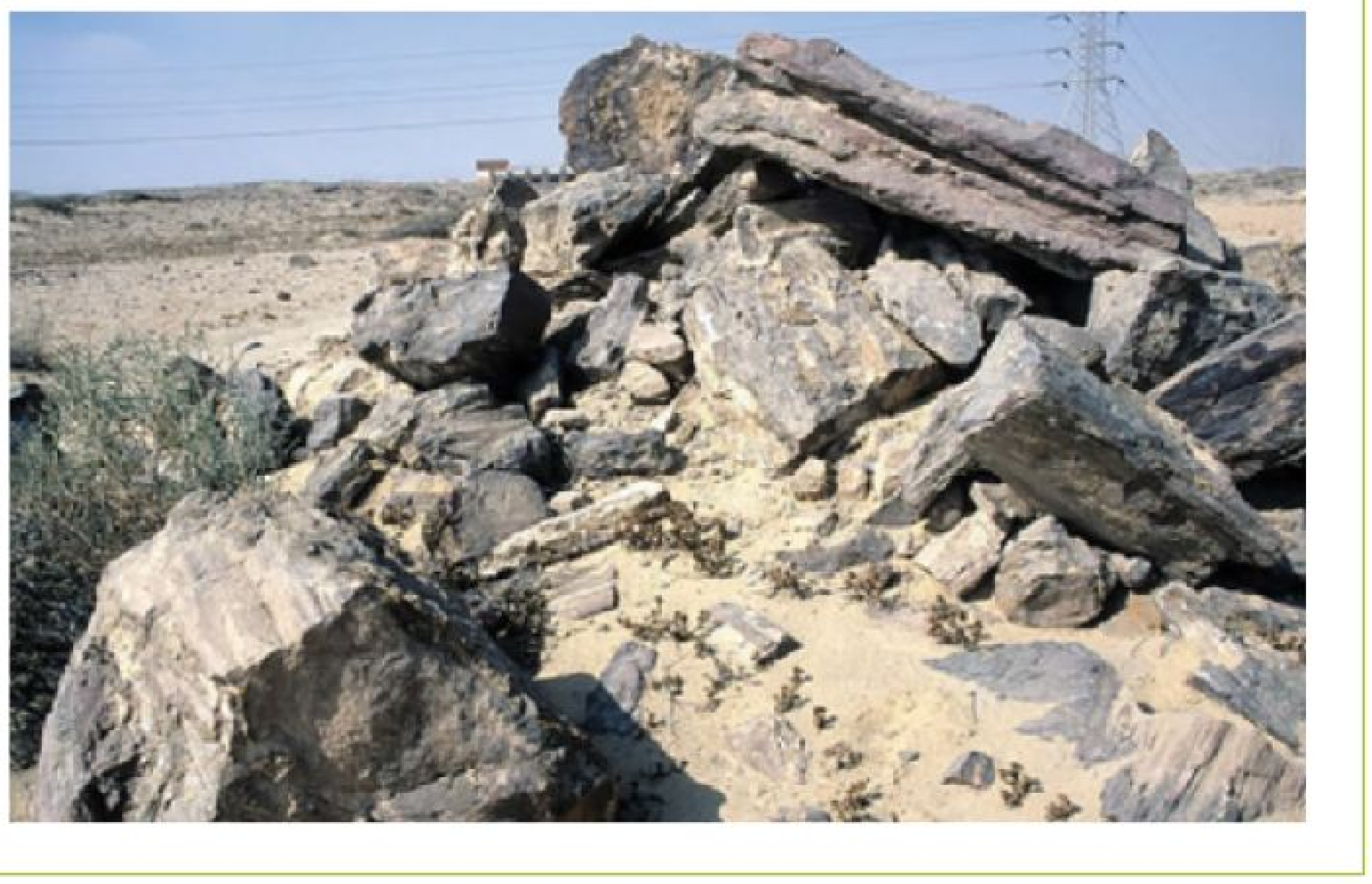
The Petrified Forest National Park near Holbrook, Arizona, is one of the biggest and most impressive petrified forests in the world. It houses nearly a dozen different types of petrified wood, ranging from conifers to ferns. It grew to today's impressive size due to the large river network upstream of the site.





Argentina's Petrified Forest National Monument is a jaw-dropping demonstration of the changes the planet has undergone in its lifetime. Before the vast Andes mountain range even existed, vegetation was everywhere, some trees reaching 100m (328ft) high. Then, geological shift created the Andes and accompanying volcanoes, burying the plant life in ash, creating an amazing petrified forest.

The petrified forest near Maadi, around 30 kilometres (19 miles) from Cairo in Egypt is quite young, the logs appearing around 35 million years ago. This was a time of geological upheaval as the Red Sea formed from the separation of tectonic plates. The forest spans about six kilometres (four miles) and was declared a protectorate in 1989 so it could be officially preserved by the Egyptian government.



What's life like in the boreal forest?

Covering nearly 20 per cent of our planet's land, how have plants and animals adapted to the cold climate of the taiga?

Boreal forest, also called taiga, covers about 17 per cent of the global land surface, encircling much of the far-Northern Hemisphere. In fact, it's Earth's biggest terrestrial 'biome' – defined as a region sharing similar climate, plants and wildlife.

The taiga experiences long, cold and dry winters with average annual temperatures hovering around freezing, from minus-five to plus-five degrees Celsius (23-41 degrees Fahrenheit). The soil is generally thin, poor in nutrients and acidic, and the majority of water arrives in the form of snow.

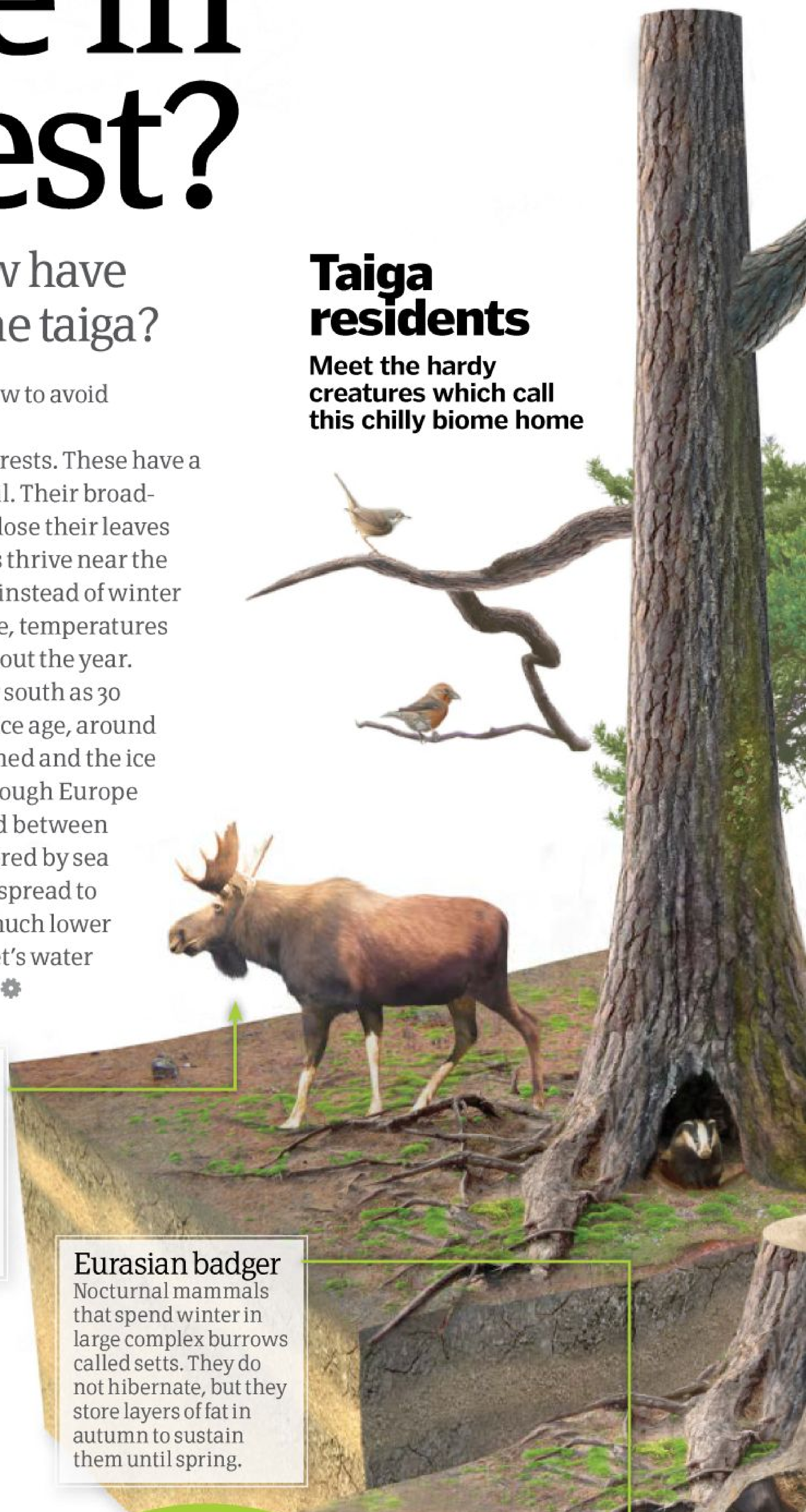
The cold climate means the most common plants are coniferous trees, which are tough enough to cope with the harsh conditions. Evergreen trees are green year-round – they keep their leaves during winter to save energy re-growing them in spring. They have waxy needles to reduce water loss when they can't draw water from the frozen ground. Needles are also dark coloured to absorb as much sunlight as possible, while their conical shape helps to shed snow to avoid branches snapping.

South of the taiga are temperate forests. These have a longer growing season and fertile soil. Their broad-leafed trees, including oak and elm, lose their leaves annually. In contrast, tropical forests thrive near the equator, with dry and rainy seasons instead of winter and summer. In rainforests like these, temperatures stay at 20-25 degrees Celsius throughout the year.

Boreal forest species existed as far south as 30 degrees north at the peak of the last ice age, around 21,500 years ago. As the climate warmed and the ice receded, the boreal forest spread through Europe and North America. Species migrated between continents across areas that are covered by sea today – for example, European trees spread to northern Scotland. Sea levels were much lower at this time because a lot of the planet's water was locked up in gigantic ice sheets.

Taiga residents

Meet the hardy creatures which call this chilly biome home



Moose
Earth's largest deer have long legs and hooves to help them navigate deep snow. Males use antlers that can span over 1.5m (5ft) to fight for females during breeding season.

Eurasian badger
Nocturnal mammals that spend winter in large complex burrows called setts. They do not hibernate, but they store layers of fat in autumn to sustain them until spring.

Boreal forest is dominated by evergreen trees like these pines in Québec, Canada

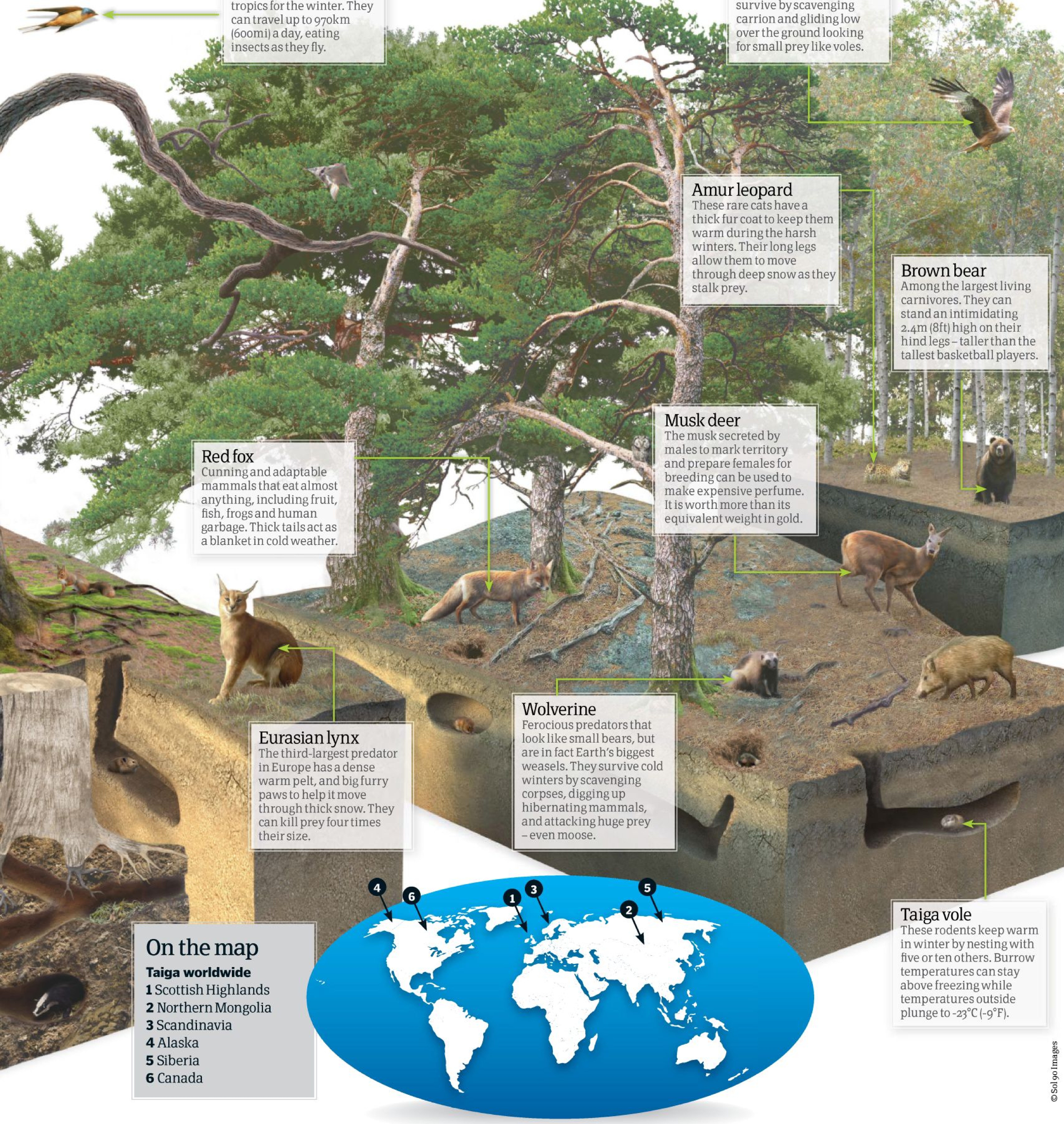
Taiga vs tundra

Tundra (pictured right) is the coldest plant and animal community on land, or terrestrial biome, and lies poleward of the taiga. Average temperatures fall below 0 degrees Celsius (32 degrees Fahrenheit) for six to ten months of the year. Rain or snowfall is less than 250 millimetres (ten inches) a year, which is actually less than some deserts.

The severe environmental conditions mean, unlike boreal forest, tundra has almost no trees. Indeed, the word tundra comes from the Finnish word 'tunturia' meaning 'treeless plain'.

Deep tree roots cannot penetrate the permanently frozen sub-soil called permafrost. When water saturates the upper layers, it gathers in ponds and bogs. Soil is shallow and poor because the cold temperatures slow down nutrient release from dead plants.

The most common vegetation found in tundra includes lichens, mosses, grasses and shrubs. Animals, such as polar bears and Arctic foxes, have adapted to the short summers and long winters by leading a nomadic lifestyle and storing fat to see them through the cold season.



Barn swallow
Songbirds that migrate from their northern breeding grounds to the tropics for the winter. They can travel up to 970km (600mi) a day, eating insects as they fly.

Red kite
Birds of prey named for their angular rust-coloured wings. They survive by scavenging carrion and gliding low over the ground looking for small prey like voles.

Amur leopard
These rare cats have a thick fur coat to keep them warm during the harsh winters. Their long legs allow them to move through deep snow as they stalk prey.

Brown bear
Among the largest living carnivores. They can stand an intimidating 2.4m (8ft) high on their hind legs – taller than the tallest basketball players.

Red fox
Cunning and adaptable mammals that eat almost anything, including fruit, fish, frogs and human garbage. Thick tails act as a blanket in cold weather.

Musk deer
The musk secreted by males to mark territory and prepare females for breeding can be used to make expensive perfume. It is worth more than its equivalent weight in gold.

Eurasian lynx
The third-largest predator in Europe has a dense warm pelt, and big furry paws to help it move through thick snow. They can kill prey four times their size.

Wolverine
Ferocious predators that look like small bears, but are in fact Earth's biggest weasels. They survive cold winters by scavenging corpses, digging up hibernating mammals, and attacking huge prey – even moose.

Taiga vole
These rodents keep warm in winter by nesting with five or ten others. Burrow temperatures can stay above freezing while temperatures outside plunge to -23°C (-9°F).

On the map
Taiga worldwide
1 Scottish Highlands
2 Northern Mongolia
3 Scandinavia
4 Alaska
5 Siberia
6 Canada

©Sol 90 Images

How do ferns grow?

How this ancient group of plants has survived for millions of years

About 450 million years ago, the first land plants emerged from the water. They were simple green flaps, a bit like modern liverworts. Later, slightly more advanced moss-like plants appeared, and these evolved into the more complex form of ferns, horsetails and club mosses. 300 million years ago, ferns and their allies dominated a world that was much wetter than today. As a result, they only needed a simple system to move water to their stems and leaves.

These ancient plants had a two-stage life cycle. The mosses and liverworts that we typically find on rocks and in damp woods are all gametophytes – the sexual stage in the moss's life cycle, which produce the equivalent of eggs and sperm, called gametes. In wet weather, the male gametes swim over the moist surface of moss leaves to fertilise the eggs. These then develop into a stalk topped by a cap. This second stage, which relies entirely on the gametophyte for nourishment, is called the sporophyte, because it produces spores like simple seeds. These are shaken from pores in the cap and blown to a new site, where they grow into new gametophytes, but these can only survive in wet conditions.

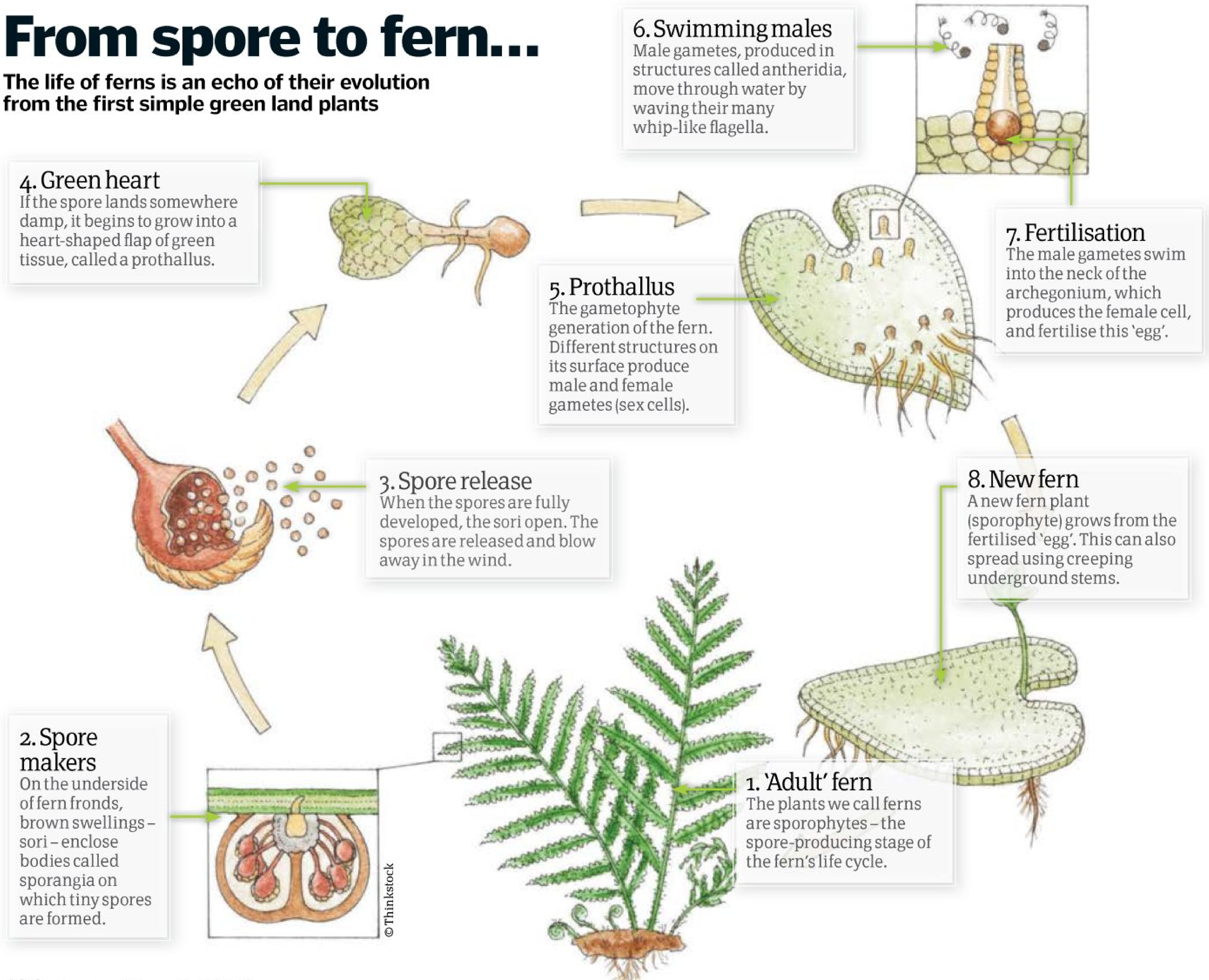
Ferns have evolved so that the sporophyte has become the dominant stage in their life. Ferns, horsetails and club mosses are all sporophytes that live freely, even in quite dry conditions. The spores the ferns release develop first into gametophytes and then these reproduce sexually to create the next generation of fern. ✻

Ferns, fossils and fuels

300 million years ago, ferns and their relations formed the main vegetation of our planet. Flowering plants did not appear for another 175 million or so years. In this Carboniferous period, the continental plates carrying North America and Europe were situated close to the equator in wet, tropical conditions. In the steamy swamps, club mosses over 30 metres (98 feet) tall grew in dense forests. The remains of these club mosses and horsetails formed much of today's coal, and many impressions of fern fronds are found as fossils in ancient rocks.

From spore to fern…

The life of ferns is an echo of their evolution from the first simple green land plants



1. 'Adult' fern
The plants we call ferns are sporophytes – the spore-producing stage of the fern's life cycle.

2. Spore makers
On the underside of fern fronds, brown swellings – sori – enclose bodies called sporangia on which tiny spores are formed.

3. Spore release
When the spores are fully developed, the sori open. The spores are released and blow away in the wind.

4. Green heart
If the spore lands somewhere damp, it begins to grow into a heart-shaped flap of green tissue, called a prothallus.

5. Prothallus
The gametophyte generation of the fern. Different structures on its surface produce male and female gametes (sex cells).

6. Swimming males
Male gametes, produced in structures called antheridia, move through water by waving their many whip-like flagella.

7. Fertilisation
The male gametes swim into the neck of the archegonium, which produces the female cell, and fertilise this 'egg'.

8. New fern
A new fern plant (sporophyte) grows from the fertilised 'egg'. This can also spread using creeping underground stems.

© Thinkstock

What makes a mushroom?

Neither plants nor animals, mushrooms and toadstools play a vital role in the natural world

Imagine an apple tree that grows entirely underground. All we ever see are apples, mysteriously appearing at the surface in autumn. That is essentially how fungi live. The main part of their structure is a network of fine threads, called a mycelium, which spreads through the soil or other substrate. Often, all we see are the fruiting bodies which appear above ground. We call these mushrooms if they are edible or toadstools if they are inedible, although there is no scientific distinction between the two.

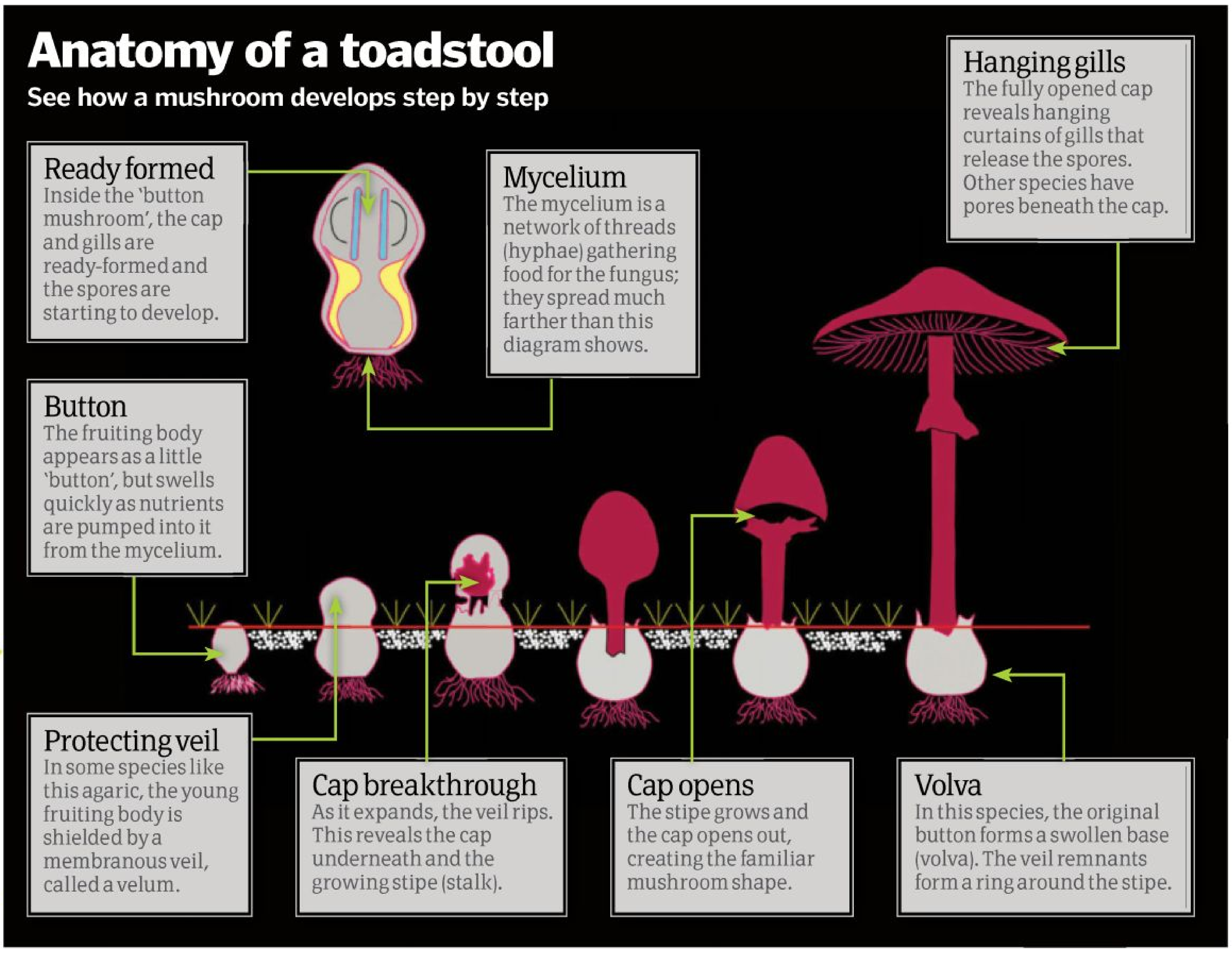
The fungal mycelium grows through its food, which might be soil, old leaf litter, dead trees, wood of living trees or even dead animals. The threads (called hyphae) can reach out huge distances to find food. Although some fungi attack and kill living plants (especially trees) and animals, many are beneficial, by decomposing dead material and releasing its goodness back into the soil.

Many trees, orchids and other plants could not grow without a fungus wrapped around and penetrating their roots. This intimate partnership, called a mycorrhiza, takes nutrients from the soil to feed the host plant and, in return, the fungus is protected from harm.

Fungi are truly ancient. The remains of plants fossilised some 400 million years ago in rocks at Rhynie in Scotland had fungal mycelia in their roots. Fungi were once classed as plants, but their lifestyle is so unique that scientists now place them in their own distinct kingdom.

Anatomy of a toadstool

See how a mushroom develops step by step



Ready formed
Inside the 'button mushroom', the cap and gills are ready-formed and the spores are starting to develop.

Mycelium
The mycelium is a network of threads (hyphae) gathering food for the fungus; they spread much farther than this diagram shows.

Hanging gills
The fully opened cap reveals hanging curtains of gills that release the spores. Other species have pores beneath the cap.

Button
The fruiting body appears as a little 'button', but swells quickly as nutrients are pumped into it from the mycelium.

Protecting veil
In some species like this agaric, the young fruiting body is shielded by a membranous veil, called a velum.

Cap breakthrough
As it expands, the veil rips. This reveals the cap underneath and the growing stipe (stalk).

Cap opens
The stipe grows and the cap opens out, creating the familiar mushroom shape.

Volva
In this species, the original button forms a swollen base (volva). The veil remnants form a ring around the stipe.

5 fantastic fungi

1 Fly agaric

This poisonous toadstool with a white-spotted red cap is familiar from fairy tales. It grows in most parts of the world, usually near birch trees because its mycelium forms a mycorrhiza with birch roots.

2 Stinkhorn fungus

When its spores are ripe, the veil splits off the cap, revealing a foul-smelling, black mass of spores beneath. The smell attracts flies that carry off the sticky spores, helping to spread the species.

3 Puffball

The caps of these fungi have thin, papery walls, perforated by pores. They contain a mass of powdery spores. Raindrops hitting the balloon-like caps cause puffs of spores to be blown out and dispersed in the wind.

4 Bracket fungus

These tough, woody fungi are shaped like a rounded shelf or a horse's hoof growing from the side of a tree. Their hyphae grow through the wood, causing it to rot; sometimes this will eventually kill the tree.

5 Dry rot

Spotting the bracket-like fruit body of this fungus in a building is bad news. By then, its mycelium will have spread through structural timbers, causing rot and requiring the building to be gutted.

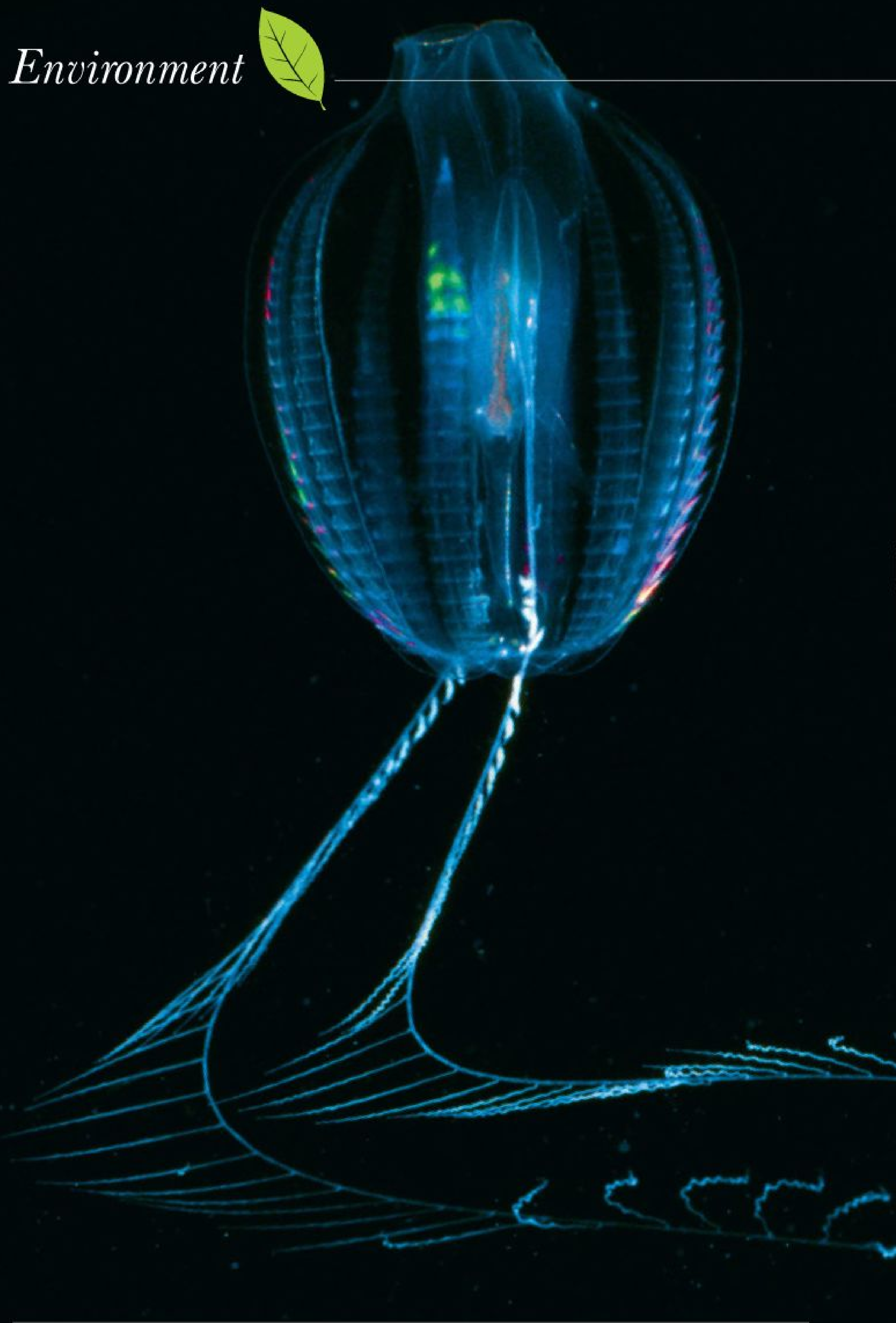
© SPL

Elephants' immense size and yearly hormone surge can make them extremely dangerous to humans

Are elephants dangerous, or are they gentle giants?

Would you feel safe around the largest land mammal walking the Earth?

To humans, elephants are very dangerous. An adult African elephant weighs up to 5.5 tons with tusks that can be 2.5 metres (8.2 feet) long and weigh 60 kilograms (132 pounds) each. They can trample you with their feet and knock you out cold with their trunk. Male elephants also undergo a surge in hormones once a year, called musth, which makes them extremely aggressive. In India alone, wild elephants kill about 200 people a year. A study from 1999 found that in just one region of India over a six-year period, 242 people were killed by wild elephants, compared to 90 by wolves, 50 by sloth bears, four by leopards and two by tigers.



Can brains be regrown?

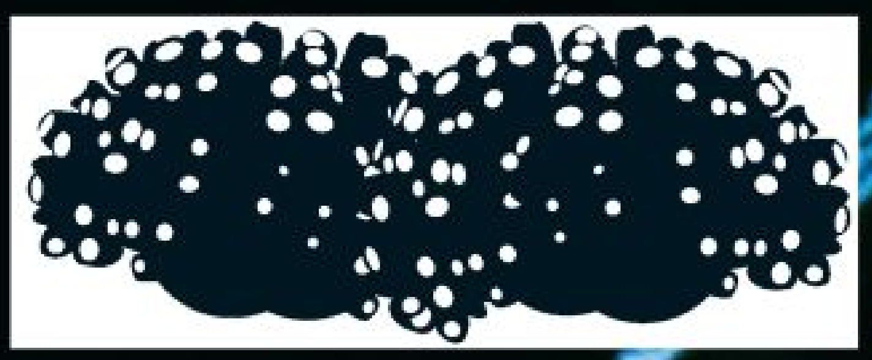
This deep-sea creature has the power to regrow its brain

Sounding like something out of a science fiction B-movie, the comb jelly has a brain like nerve net that can regenerate itself in just three and a half days. How does it do this? Scientists are claiming that this alien-like creature has a completely different chemical language and processes to any other animal. Unlike in humans where neurons are very difficult to replace, these organisms can regrow the nervous system very efficiently. Research is being undertaken to see if this can be harnessed to help with diseases such as Alzheimer's and Parkinson's, which harm the nerves and the brain.

Bizarre brains

Leeches
The blood-sucking parasites have 32 brain segments in their tiny bodies.

Sea squirts
Once they attach themselves to coral, they eat their own brain.



Cav King Charles Spaniel
Due to over-selective breeding, its skull is too small to accommodate the brain in a third of the dogs.

How are plants cloned?

Find out how we make identical copies of plants and what benefits this offers

The process of cloning plants has been used in agriculture for centuries, as communities split roots and took cuttings to efficiently create multiple plants.

Taking a cutting from near the top of a plant, placing it in moist soil and covering it will enable a new offspring to grow with the same genetic code as the parent from which it was taken. This method of cloning is very easy to do and is common among casual gardeners and industrial farmers alike. However, in more recent years the cloning of plants has madeits way into the laboratory.

Responsible for that shift is Gottlieb Haberlandt, a German physiologist. At the beginning of the 20th century, he was the first to isolate a plant cell and then try to grow an exact replica of the parent. His attempt ultimately failed, but the experiment showed enough promise to convince others to follow in his footsteps. The likes of Hannig in 1904 and Kolte and Robbins in 1922 ran successful experiments in which they also cultured plant tissue to create new versions.

The main benefit of cloning flora is that growers are able to guarantee disease-free plants by cultivating cells from strong and healthy ones, leading to higher and more reliable crop yields. By taking cuttings from proven strains, a farmer can be sure his next generation of crops is equally successful.

Back inside the lab, the development of cloning through cultivating plant tissue allows for species to even be adapted and improved. However this genetic modification (ie GM crops) remains a controversial topic, as some experts argue we can't predict what the consequences of this human interference will be.

Plant cloning can be as basic as snipping off a stem from a begonia or as complex as growing a tomato plant in a solution of inorganic salts and yeast extract, but nevertheless the process by which you can create two plants out of one remains a triumph of natural science.

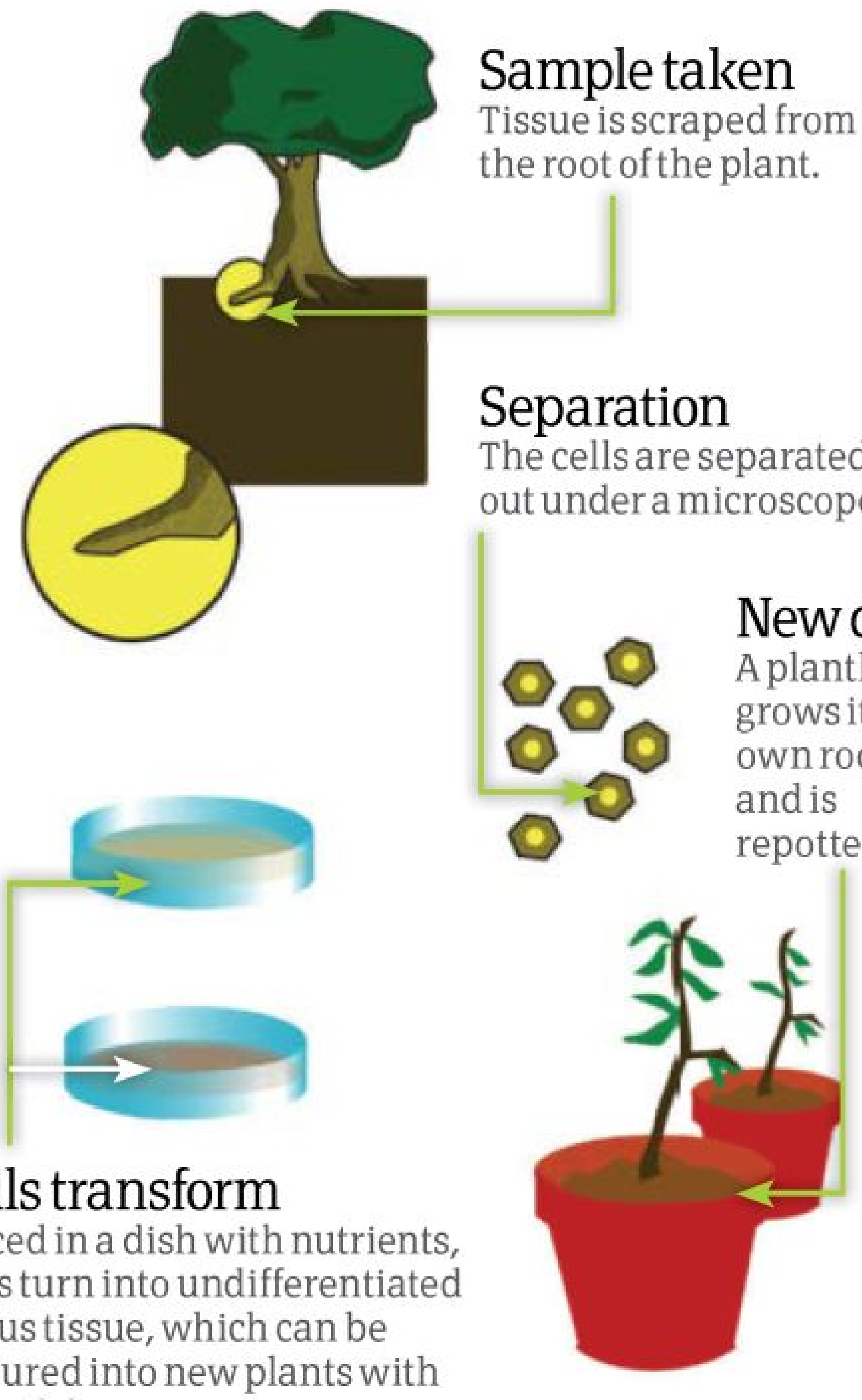
Dolly lived to be almost seven years old

What about animals?

Most of us are aware of Dolly the sheep, the first animal cloned from an adult cell, but artificial cloning dates back to the late-19th century. Hans Dreisch created two sea urchins by separating two urchin embryo cells from which two offspring grew, proving that DNA is not lost through separation. The next big development came in 1952 when a frog embryo was cloned by inserting the nucleus from a tadpole's embryo cell into an unfertilised frog egg cell. But the creation of Dolly in 1996, cloned using a mammary cell from an adult sheep, led to hopes that one day we might be cloned as well. There's still a while until a human can be replicated, but Dolly represented a huge leap forward in terms of cloning possibilities.

Plant duplication guide

Discover how plants can be cloned in the lab through the process of cell separation



Sample taken
Tissue is scraped from the root of the plant.

Separation
The cells are separated out under a microscope.

New digs
A plantlet grows its own roots and is repotted.

Cells transform
Placed in a dish with nutrients, cells turn into undifferentiated callus tissue, which can be cultured into new plants with growth hormones.

Laboratory plant cloning is used for scientific research and to develop stronger strains

© Alamy; SPL

How does plankton glow in the dark?

An amazing sighting of luminous sea creatures off the Welsh coast

Best known as a food of choice for fish and whales, plankton have a few tricks of their own too. Chemical reactions known as bioluminescence occur in their body, which gives them the ability to glow blue, green, red or orange. The reaction produces energy, which makes particles vibrate and oxidise to create light. The lamination is used to warn off predators with the flash confusing, scaring and putting off anything that tries to eat the critters. Probably doesn't work that well on the hungry whales, mind you.

Luminous plankton sounds like science fiction, but is completely real

How do deserts grow?

Discover why farmland across the planet is being swallowed at a terrifying rate by creeping sands…

Each year 0.2 per cent of usable farmland is lost from arid regions worldwide. That may not sound like a lot, but pressure on food and water resources is growing exponentially. Indeed, Earth's population is predicted to increase by a staggering 4 billion people by the year 2100.

Desertification occurs when farmland is overused in dry climates with fragile ecosystems already vulnerable to drought. Many affected areas are home to the poorest people in the world.

Livestock overgraze grass and wear away earth with their hooves, while intensive arable farming depletes nutrients in the soil. Toxic salts build up and farmland becomes waterlogged when fields are overwatered by irrigation. Water and wind make the problem even worse by removing nutrient-rich soil, gradually leaving nothing but a bare desert behind.

No continent is immune from desertification. Around a third of our planet is directly affected and population pressure is typically the root cause of it.

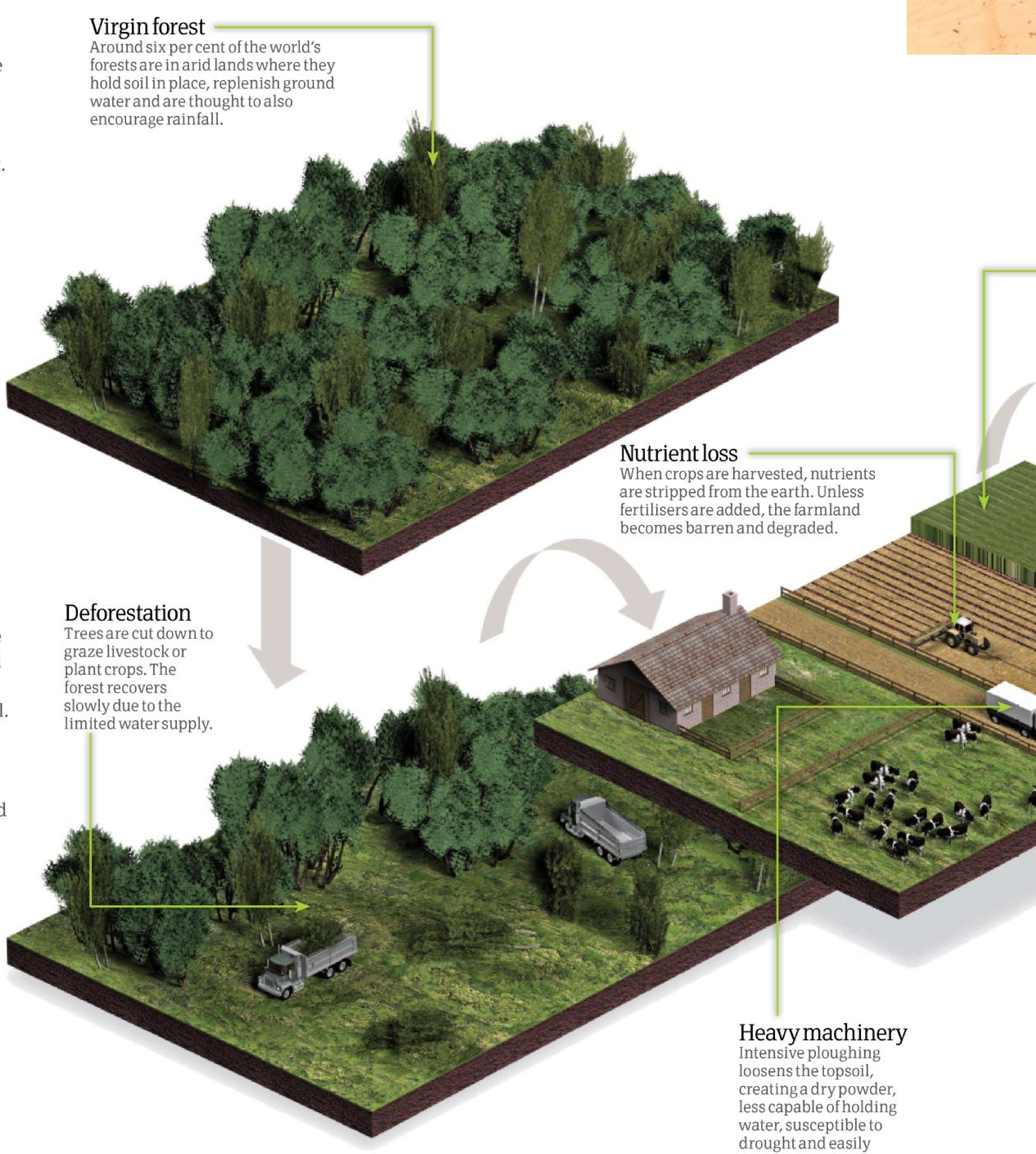
Land degradation is not a new problem, though. Studies suggest the collapse of the Mayan civilisation in 900 CE was triggered by population growth followed by crop cultivation on steep slopes with fragile soil.

Desertification has devastating effects on people and the environment alike. Farmers face famine or the threat of disease if they migrate away from depleted farmland. Dust from the affected land can also cause lung diseases. In China, sandstorms and dunes from the advancing Gobi Desert swallow up entire villages and affect air quality in Beijing some 80 kilometres (50 miles) away.

In Africa's Sahel, desertification increases drought risk too; vegetation dying back exposes the pale sand, which reflects more heat, reducing updraughts of damp air that generate clouds and rain, so once it begins, desertification is self-propagating.

Farmland to wasteland

See how intensive agriculture can transform a fertile landscape into a barren terrain



Virgin forest
Around six per cent of the world's forests are in arid lands where they hold soil in place, replenish ground water and are thought to also encourage rainfall.

Deforestation
Trees are cut down to graze livestock or plant crops. The forest recovers slowly due to the limited water supply.

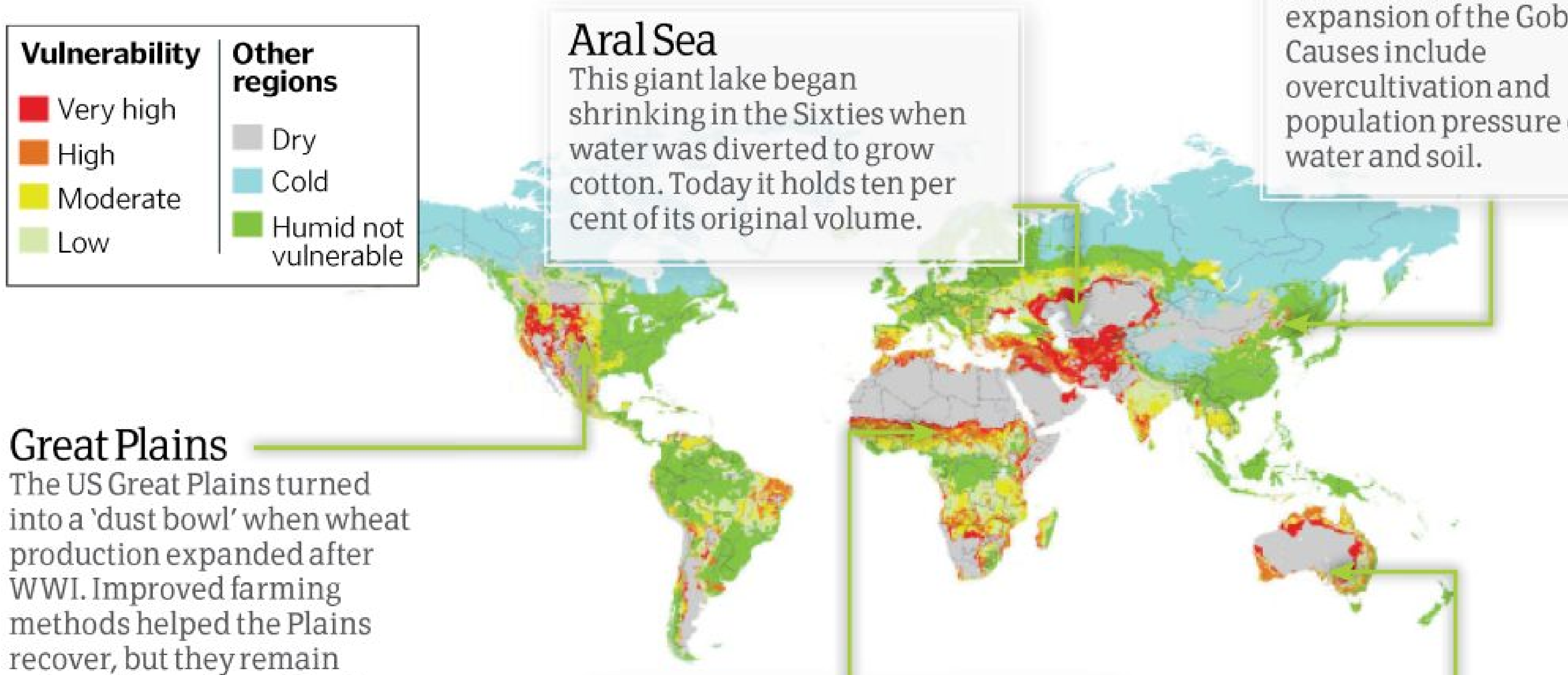
Nutrient loss
When crops are harvested, nutrients are stripped from the earth. Unless fertilisers are added, the farmland becomes barren and degraded.

Heavy machinery
Intensive ploughing loosens the topsoil, creating a dry powder, less capable of holding water, susceptible to drought and easily washed or blown away.

The Aral Sea is an extreme example of desertification, where the water has receded so much that many ships now sit rusting miles away from the once-huge lake

Desert expansion around the globe

What places on Earth have been most affected by desertification?



Great Plains

The US Great Plains turned into a 'dust bowl' when wheat production expanded after WWI. Improved farming methods helped the Plains recover, but they remain vulnerable to desertification.

Aral Sea

This giant lake began shrinking in the Sixties when water was diverted to grow cotton. Today it holds ten per cent of its original volume.

Gobi Desert

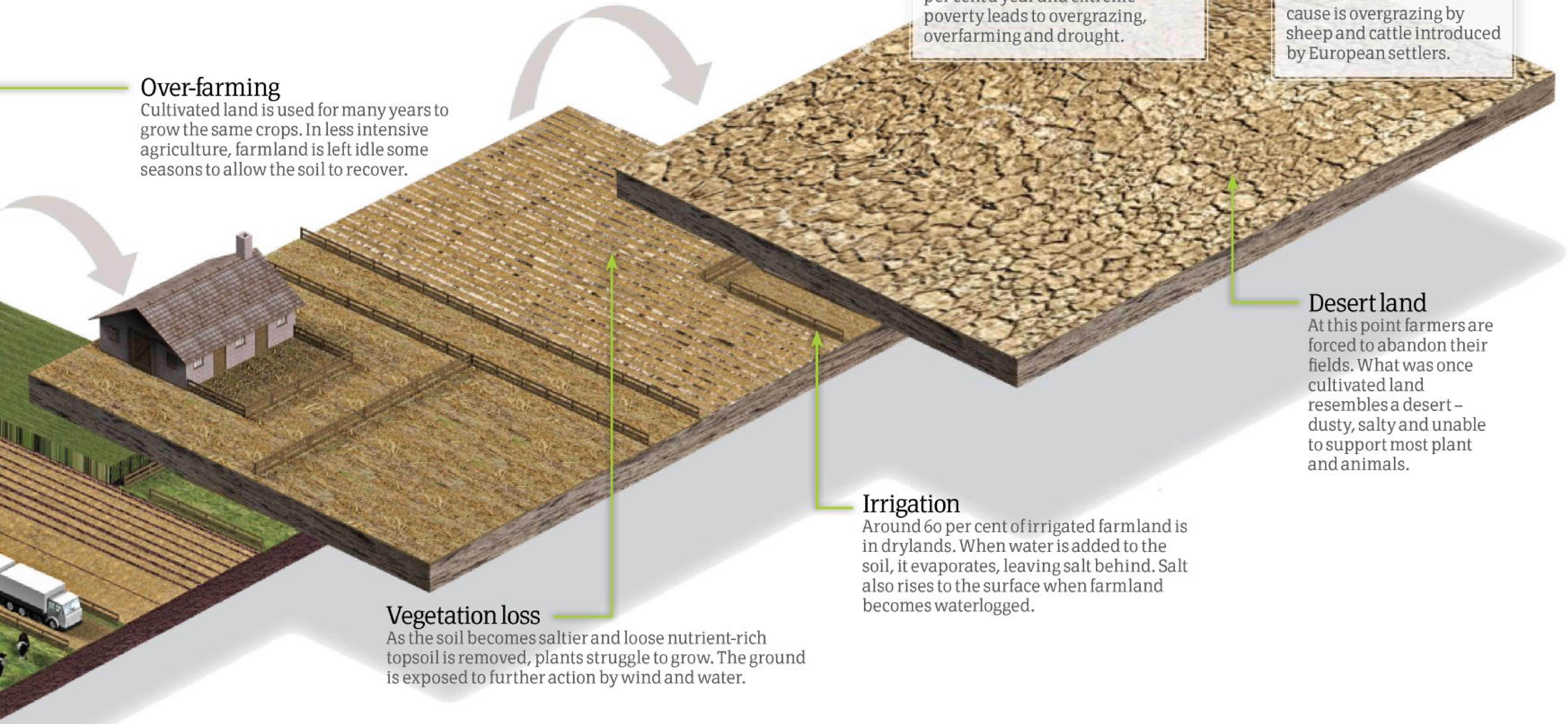
Around 3,600km2 (1,400mi2) of China becomes desert each year, due to the expansion of the Gobi. Causes include overcultivation and population pressure on water and soil.

Sahel region

Approximately 40 per cent of Africa is affected by desertification. Population growth of three to four per cent a year and extreme poverty leads to overgrazing, overfarming and drought.

Australia

An estimated 42 per cent of Australia is affected by desertification. The main cause is overgrazing by sheep and cattle introduced by European settlers.



Over-farming

Cultivated land is used for many years to grow the same crops. In less intensive agriculture, farmland is left idle some seasons to allow the soil to recover.

Vegetation loss

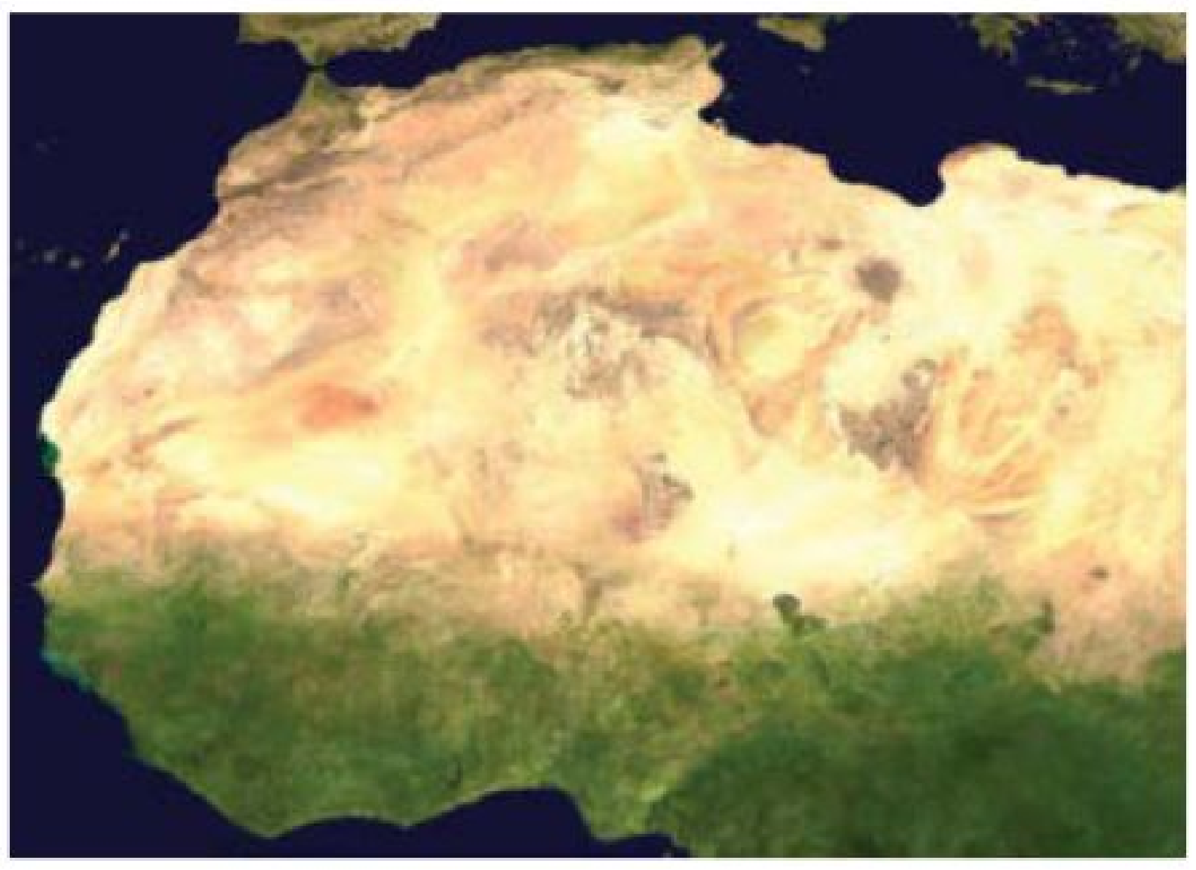
As the soil becomes saltier and loose nutrient-rich topsoil is removed, plants struggle to grow. The ground is exposed to further action by wind and water.

Irrigation

Around 60 per cent of irrigated farmland is in drylands. When water is added to the soil, it evaporates, leaving salt behind. Salt also rises to the surface when farmland becomes waterlogged.

Desert land

At this point farmers are forced to abandon their fields. What was once cultivated land resembles a desert – dusty, salty and unable to support most plant and animals.



How can we fight desertification?

Reversing desertification depends on tackling human exploitation of land by providing sources of income. Imagine a wall of trees and shrubs – 8,000 kilometres (5,000 miles) long and 15 kilometres (nine miles) wide – snaking west to east across Africa. The Great Green Wall project began in 2011 to counter desertification on the Sahara Desert fringe. Since then, 12 million drought-resistant acacia trees have been planted in Senegal alone.

Large-scale planting schemes were used to tackle desertification in 1935 during the Dust Bowl in the United States too. China initiated its very own green-wall project in the year 1978, which afforested 9 million hectares in the first ten years.

Large forested areas replenish the water table, act as wind breaks to stop sand dunes, and may increase rainfall; for example, an estimated 60 per cent of Amazon rainfall is created by the rainforest itself. Advocates of the African green wall believe it can even counter terrorism, providing jobs by producing gum arabic from acacia.

Other techniques to fight desertification include improving irrigation techniques, applying bacteria to dunes and introducing sand fences and pools.

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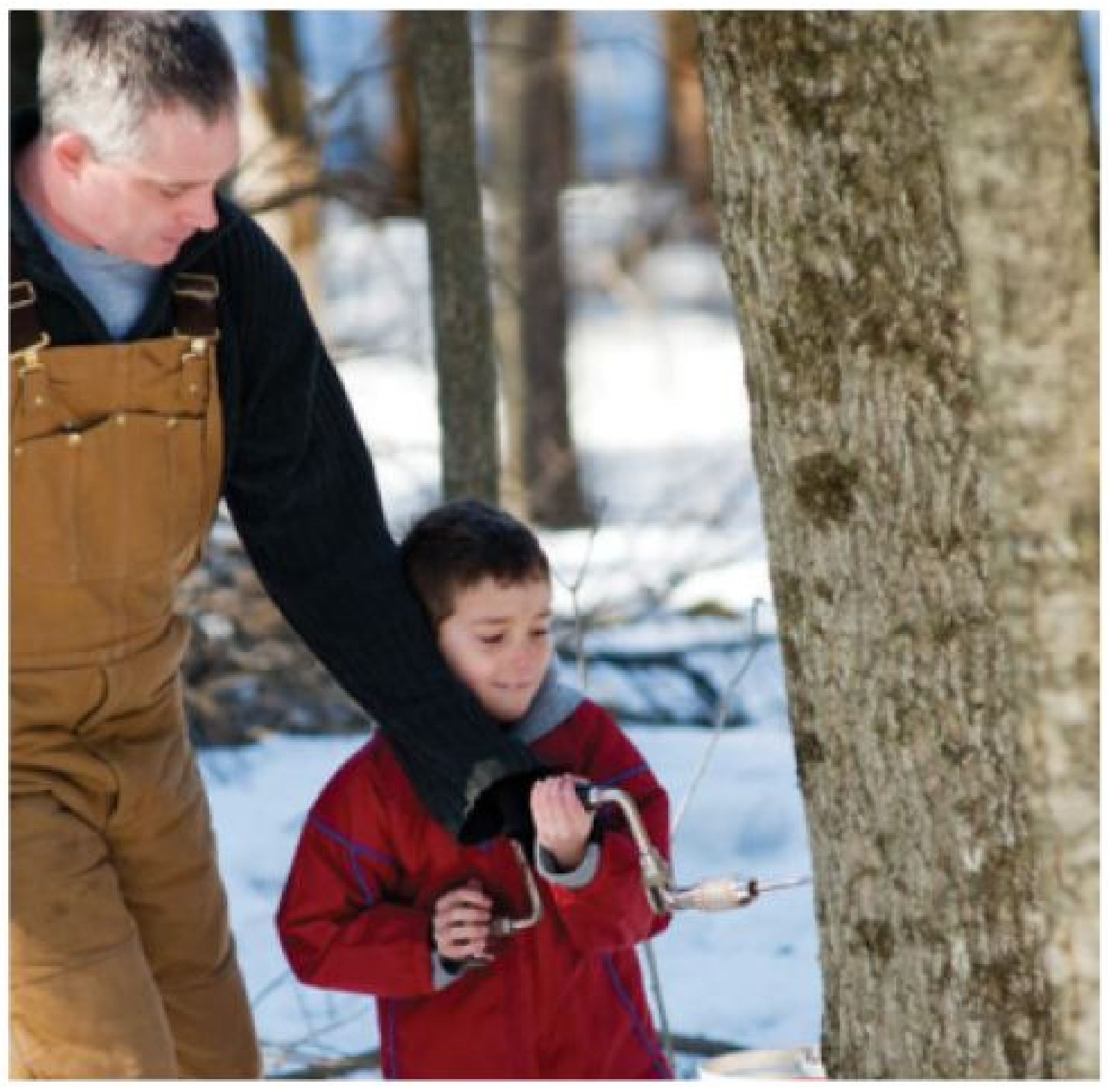
How do you tap maple syrup?



The first thing you need is a maple tree. The roots of the tree store starch, which gets converted into sugars to feed the tree, allowing new buds to grow. Sap moves up from the roots of the tree, so finding a nice thick root is best. With a hand drill pointing slightly upward, drill about the same length as your little finger into the tree until sap starts to drip out. Hammer a spout into the hole until it sits snugly, preferably one with a hook so you can hang a bucket to collect the sap. Cover the bucket. Take it home. Boil it. Make pancakes.

How is silk manufactured?

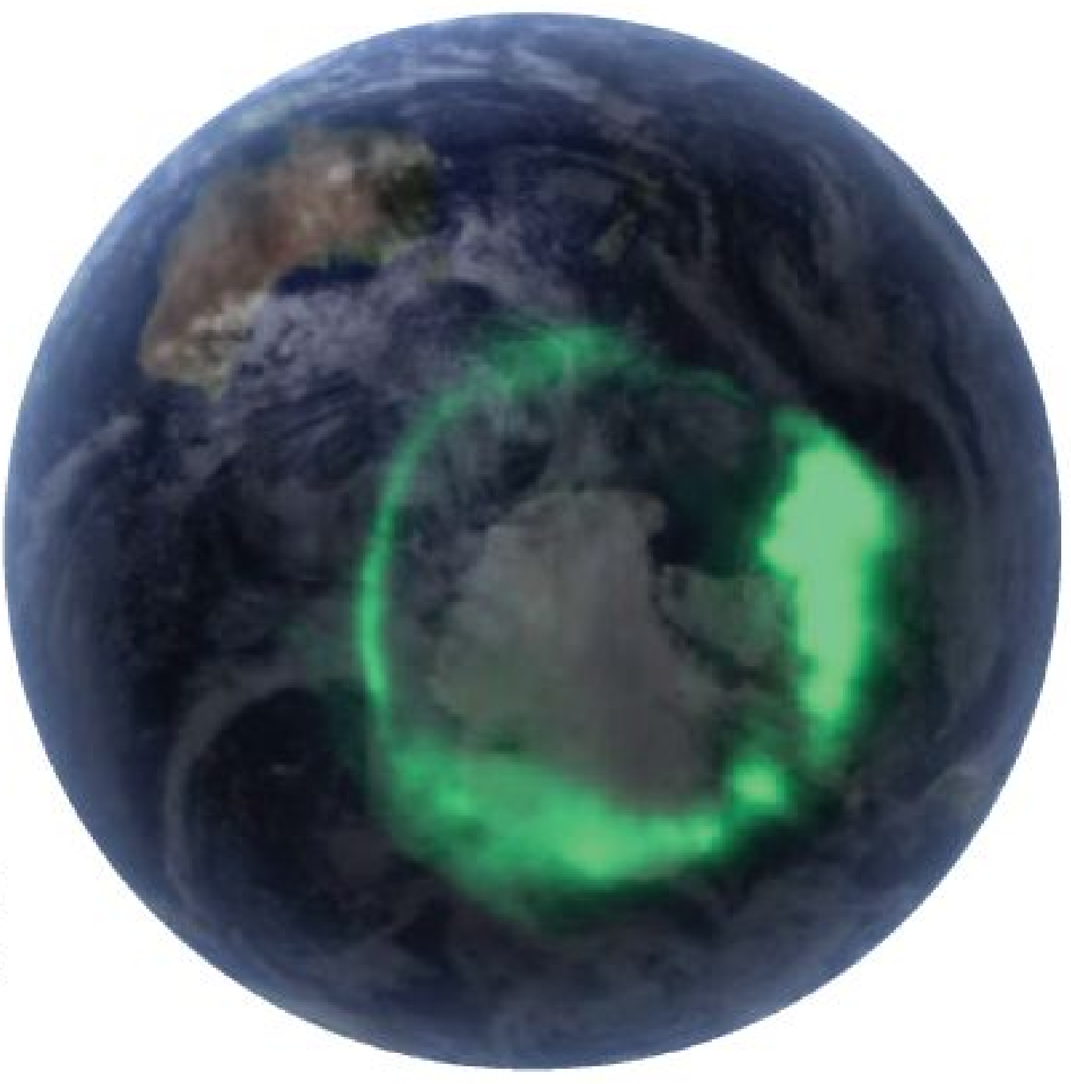
Silkworm caterpillars secrete silk as a liquid protein called fibroin. This stiffens into a solid filament on contact with air. The caterpillar glues this into a cocoon, using a different sticky protein, called sericin. But before the caterpillars get a chance to change into moths, silk farmers boil the cocoons in water to kill the caterpillars and dissolve the sericin coat. The boiled cocoons are combed until the loose end unravels and then the thread is fed onto spools and spun. It takes five to ten silk fibre strands to make a single thread and 6,000 caterpillars to manufacture a single kilogram (2.2 pounds) of silk.

How do tumbleweeds survive?

Tumbleweeds are ordinary plants with leaves and roots for most of their lifecycle. The tumbling is just a way of scattering their seeds. Dandelions and thistles produce seeds that separate from the plant and are blown by the wind. In a tumbleweed, all the seeds are carried together by the whole plant. When the tumbleweed's seeds are mature, the whole plant dies back, becoming desiccated and much lighter, which makes it easier to travel. The stem detaches from the roots in the same way that trees drop their leaves in autumn. The top part then rolls along the ground, dropping seeds as they are shaken loose by the ride.

> *"When the tumbleweed's seeds are mature, the whole plant dies back, becoming desiccated and much lighter, which makes it easier to travel"*

Are polar auroras stronger at the North Pole?



They're not actually stronger at the North Pole, but they are seen more frequently because the aurora borealis, or northern lights, tend to happen over more populated areas than their southern equivalent, the aurora australis. The poles aren't the best place to see auroras anyway – they tend to form in broad 'auroral ovals', around 10-20 degrees from the pole, relating to the region where magnetic field lines leading to or from the pole pass through the upper atmosphere – the auroras themselves appear as energy-rich particles from space are drawn down along these field lines and collide with particles high in the air to emit beautiful glows.

Which are smarter: cats or dogs?

There's really not much in it. The ratio of brain to body size is slightly higher for dogs than cats, which may be because dogs are a social species and have evolved some extra brain to handle more complex communication and interaction. But cats have almost twice as many neurons in their cerebral cortex, the area involved in memory, attention and perception. Cats are harder to train, and won't fetch things or guard their owner. But does that mean dogs are smarter, or cats are?

Can animals count?

When we add up the apples in a basket, we step through the sequence of numbers until we run out of apples. This requires the language ability to remember the words for each number and their order. Animals probably can't do this. But there is another sort of counting where you intuitively judge the number of objects without starting from one. This is called subitising and most humans can do it for four or five objects and sometimes more. Many animals have this skill too, even quite primitive ones. Red-backed salamanders can tell the difference between one, two and three. Mosquitofish can manage up to four. Ring-tailed lemurs can also put groups of different numbers of objects in order of size. They can tell which group is larger, but only when one group is at least twice as big as the other.

Why do flocks of geese fly in a V-formation?

It's more efficient. Every time a bird flaps its wings, it generates a vortex of air at each wingtip that spirals behind the bird, widening as it gets farther away. A bird following behind can position itself at the edge of this vortex, at the point where the air is circling upwards. This updraught provides lift, which means that the bird needs less energy to stay aloft. For large birds like geese, the effect can reduce drag by up to 65 per cent. They take it in turns to fly at the front, so that each one benefits from the vortex effect.

* * *

How do plants underwater differ from plants on land?

Freshwater aquatic plants have to deal with a much darker environment, with lower levels of available CO2. The scarce light is already mostly mopped up by the soup of single-celled algae floating in the water. So aquatic plants either have extremely thin, feathery leaves to maximise their surface area, or they try their best to get their leaves out the water. Water lilies have large, flat leaves that float; reeds poke their leaves all the way up into the air. The main adaptation they have for this life is called aerenchyma. This is a spongy, air-filled tissue in the stems that stores and transports oxygen around the plant. The oxygen isn't absorbed from the surrounding water; instead it's produced by the plant itself as a by-product of photosynthesis.

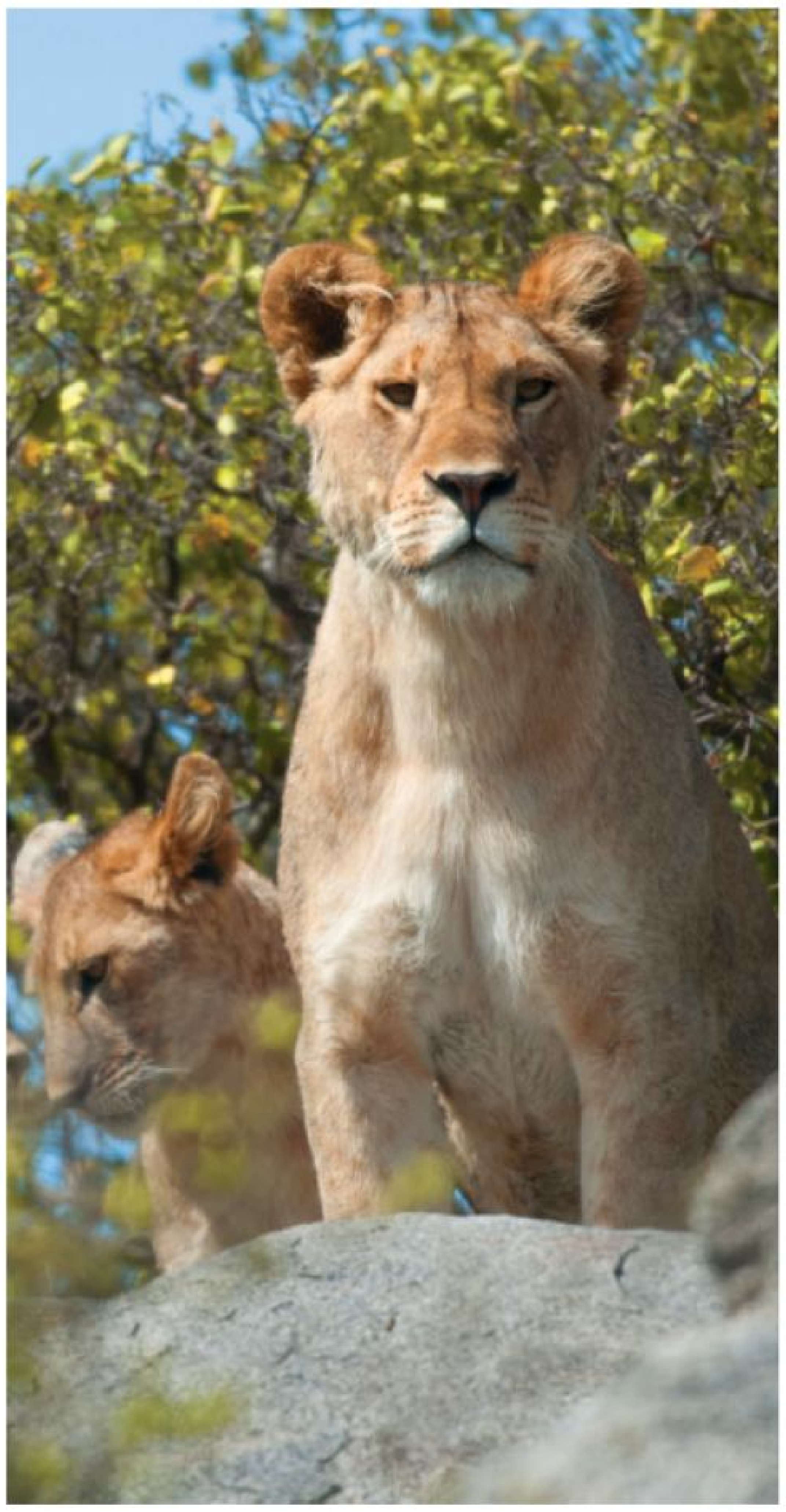
Why are bees making blue honey?

When bees in the French town of Ribeauville started producing blue and green honey in 2012, dyes from an M&M waste plant were to blame. While bees produce different shades of honey depending on which flowers they collect nectar from, blue honey was previously unheard of. Beekeepers discovered their bees had switched food sources, shunning local flowers in favour of brightly coloured, sugary M&M shell fragments being processed at a neighbouring biogas plant. Bees then transformed these sugars – along with the dyes – into honey. The waste-processing plant has since tidied away any uncovered waste containers, spelling the end of the blue honey.

* * *

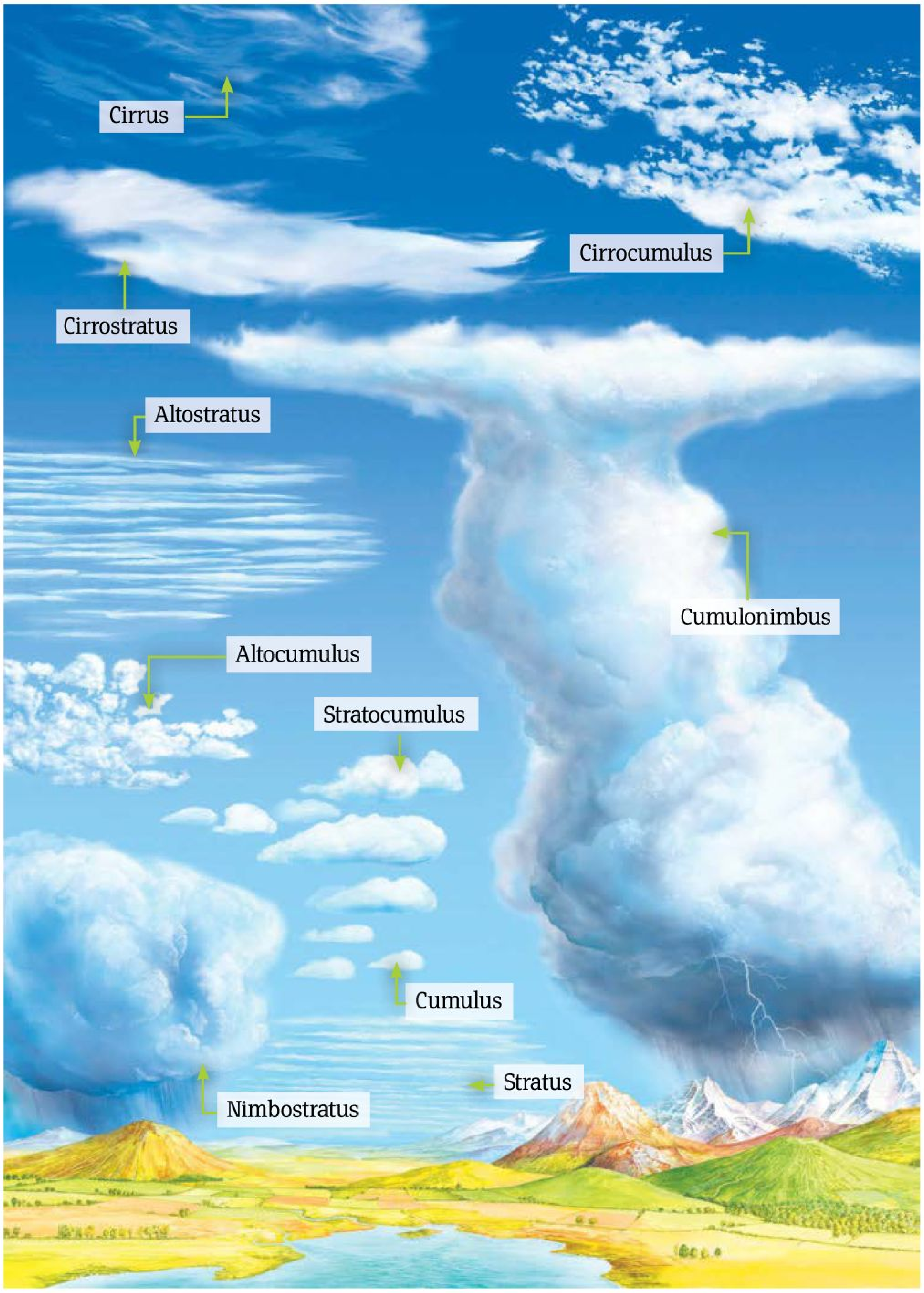
Where does slate come from?

Slate is a metamorphic rock. The slate in North Wales began as mud that settled at the bottom of the sea some 500 million years ago. As new layers settled on top, the lower ones eventually get compressed to form shale. Over millions of years the tectonic plates shifted and wrinkled to form the Welsh mountains and the shale became heated and compressed. This caused the minerals in the shale to partially melt and reform as thin sheets of mica and quartz. Because of the particular way the crystals grow, the layers of slate are at right angles to the original shale layers.



I've heard dolphins rescue people but do other animals?

In 2004, eight-year-old Amber Mason was saved from the tsunami in Thailand when a young elephant carried her to safety. But this is less impressive when you realise that Amber was already riding the elephant on the beach when the wave struck. Similarly, cats have accidentally saved their owners lives by meowing loudly when the house is on fire, but they were probably actually meowing to be let out themselves. Nevertheless, genuine animal rescues do sometimes happen. In 2007, Scottish farmer Fiona Boyd was violently attacked by one of her cows who thought her calf was threatened. Her horse Kerry rode to the rescue and kicked at the cow to drive it off. And in 2005, lions saved a 12-year-old girl in Ethiopia by scaring away her kidnappers and then standing guard over her. It's not clear whether they would have eaten her if the police hadn't turned up though.



Why are there so many cloud types?

The air temperature drops as you get higher and convection currents create distinct layers within the atmosphere, so the appearance of a cloud depends on where it forms. The highest-altitude clouds are composed of tiny ice crystals. These clouds are diffuse enough to be partly transparent and so light that they are easily blown into wispy shapes by air turbulence. Between 2,000 and 6,000 metres, clouds are mainly composed of water droplets, which absorb more light so they appear more opaque, and the attraction between droplets tends to keep clouds grouped together into rounder shapes. Advancing weather fronts can create bands of cloud like waves rolling onto a beach. Below 2,000 metres, the droplets clump together into larger drops that absorb enough light to appear dark grey and the clouds are affected by convection currents rising off the ground, flattening the underside.

Are UK red squirrels starting to recover?

Red squirrel numbers are increasing, particularly in Anglesey and the north-east of England. The red squirrel had been declining since the grey squirrel was introduced from North America 140 years ago. Grey squirrels thrive better in British woodland as they can eat acorns, which reds cannot. They also carry the squirrel pox virus, which only affects red squirrels. A determined effort to selectively kill grey squirrels in certain areas has allowed the red squirrel to recover slightly. There are still only about 140,000 red squirrels in the UK, compared with over 2.5 million greys.

What are rip tides?

The term 'rip tide' is a misnomer as it refers to a narrow directional flow of water that has nothing to do with the gravitational attraction of the Sun and Moon. When waves are pushed against the shore by high winds the water can respond to the resistance that solid ground generates by travelling parallel to the coastline. If some of it finds an underwater trench or a gap in a sand bar, it can be channelled rapidly back out to sea, pushed on by the force of incoming waves. As this all occurs beneath the surface, it can catch people unaware and so they often get swept out too.

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154 What went wrong at Chernobyl?
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157 What was the role of court jesters?
157 How did Roman currency work?
158 What's inside the Mary Rose?
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161 How was colour television invented?
161 How did the first photobooth work?
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History

Q&A

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172 Bitesize Q&A

How is a WWII plane flown?

Get into the aircraft that trained pilots for WWII

It's the summer of 1940 and the German Luftwaffe is preparing to launch a mass air attack on Southern England. If they are victorious, Britain will be open to a land invasion and Blitzkrieg will be upon the British Isles. Luckily, brave and skilled RAF pilots take down the Messerschmitts in their Spitfires and Hurricanes, so the German Operation Sea Lion never materialises. But how were our pilots so skilled at air-to-air combat?

On a glorious day on the south coast, we will be over 1,200 metres (4,000 feet) in the air learning to fly like it's 1940. The plane taking flight today is not a Spitfire or a Hurricane; in fact it's not even a fighter at all. Instead it's the official World War II training plane for the RAF, the Harvard T-6, a Canadian-built Noorduyn model. Before we go skyward, we meet pilot Matt Hill who shows us the aviation ropes.

"The Harvard was used for advanced training, gunnery practice and blind flying, it had less speed and power than the Spitfire and the Hurricane as it was a trainer, not a fighter", Matt says, shortly after delivering a crash course on how to fly a plane. How It Works isn't going to be just a passenger on this flight – when we're in the air, we will actually have control of the plane.

Before we take to the skies it is important to know the history behind the aircraft. The Harvard was the second step in a RAF fighter pilot's training.

> "The Harvard was used by 30 countries as part of their respective air forces"

The statistics...
Harvard T-6/North American T-6 Texan

Length: 68.5m (28ft)

Wingspan: 12.8m (42ft)

Seating: Tandem

Power: 450kW (600hp)

Engine:
Pratt & Whitney
R-1340 Wasp

Propeller:
Hamilton Standard Two-Blade
12D40 Propeller

Top speed
338km/h (210mph)

A fleet of T-6s in 1941 ready for training drills at Randolph Field, Texas

RAF fighter aces during the Battle of Britain

NAME	AIRCRAFT	KILLS
Pilot Officer Eric Lock	Spitfire	21
Flight Lieutenant Archie McKellar	Hurricane	19
Sergeant James Lacey	Hurricane	18
Sergeant Josef František	Hurricane	17
Flying Officer Witold Urbanowicz	Spitfire	15

Prior to this, a budding pilot would take to the skies in a Tiger Moth biplane. This aircraft would be used for a four-and-a-half-hour training session to hone the skills and art of flying before ramping up the power in the Harvard. Matt explains: "This plane (the Harvard) has a hydraulic system, brakes, a tail wheel and flaps, which the Tiger Moth doesn't. People who have flown the Mustang (US WWII fighter plane) say it is very, very similar." The Harvard was used by 30 countries as part of their respective air forces and the last military usage was as recent as 1995 in the South African armed forces.

On inspection of the Harvard, it is obvious this striking machine is almost entirely unchanged since the 1940s. In fact, a fresh coat of paint is literally the only difference. The first production model flew in 1938 and its successful test flight convinced the British to order over 300 for training purposes. Far from a relic, the original instruments are all still in complete working condition and the dual cockpits are exactly how they would have been in the war. With that, Matt calls an end to the chitchat as the runway beckons. The Top Gun-esque suit is donned and into the skies we go.

The flight itself lasted 40 minutes. First, we undertook a circuit of the airfield and witnessed some breathtaking views of the nearby towns of Chichester and Bognor Regis. There wasn't much time to take in the sights, however, as it was now our turn to take the reins. Matt prepared the plane for a change in control by maintaining a steady speed and making the plane level. With a slight shunting motion, the craft was now in our hands. The Harvard is controlled by a central stick which you move in the direction you want the plane to go. The stick was incredibly sensitive and a slight movement to either side would alter the plane's flight path considerably. It felt very tense being in a tiny vehicle in a huge expanse of sky.

After the short solo journey, it was time to relinquish control and hand over to Matt, who would now do some extreme aerobatic manoeuvres. We began with a full loop, which gave the experience of around 3g's worth of force. Next up was the barrel roll, which was followed by twists and dives that resulted in a similar amount of g-force. The only way to describe the feeling is to imagine the biggest and fastest roller coaster you've been on and then multiply it by ten.

Leaving Goodwood, you couldn't help but wonder how the RAF performed these amazing moves, all while engaging in warfare with the mighty Luftwaffe. It boggles the mind that these brave men did this just a touch over 70 years ago. The Harvard T-6 is a wonderful machine and undoubtedly a key component in the RAF having the skill to win the Battle of Britain and halt the German advance.

To try your hand at flying a World War II plane for yourself, visit **www.goodwood.co.uk/aviation** for more information.

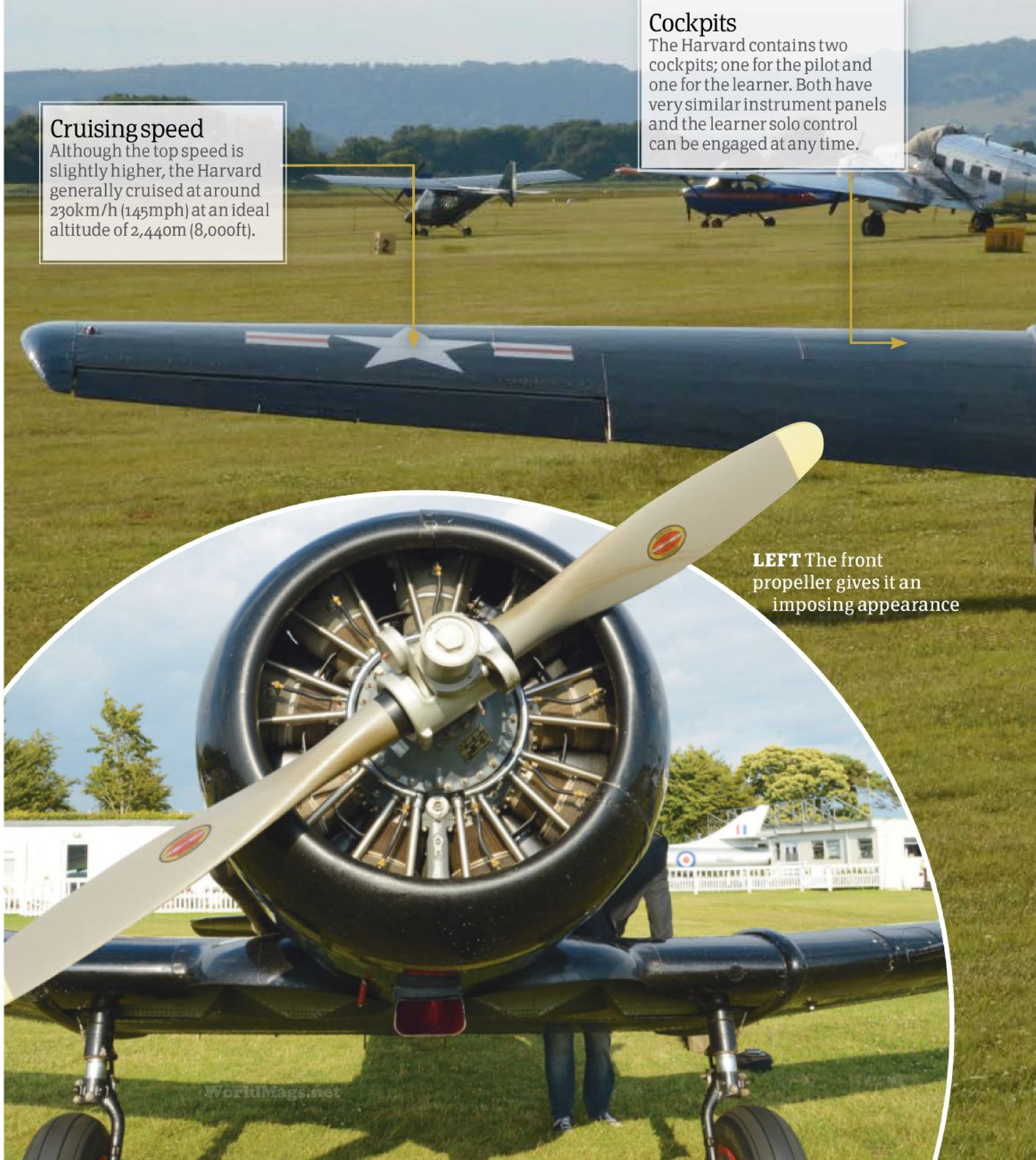
The Harvard's modern cousin

On the day, we also had the chance to test out another plane, the Cessna 172S Skyhawk, which is one of the planes used currently to train new pilots. However, the one most like the Harvard is the Swiss-built Pilatus PC-21. Used to train modern-day fighter pilots, the PC-21 provides an ideal introduction to flying jet-based fighters. It can be used for both beginner and advanced training, using a turboprop engine that uses a propeller flown by a turbine. It can reach speeds of up to 685 kilometres per hour and current customers include the air forces of Singapore and the Royal Saudi Air Force.

The Cessna 172S Skyhawk, a new training plane

The Harvard: inside and out

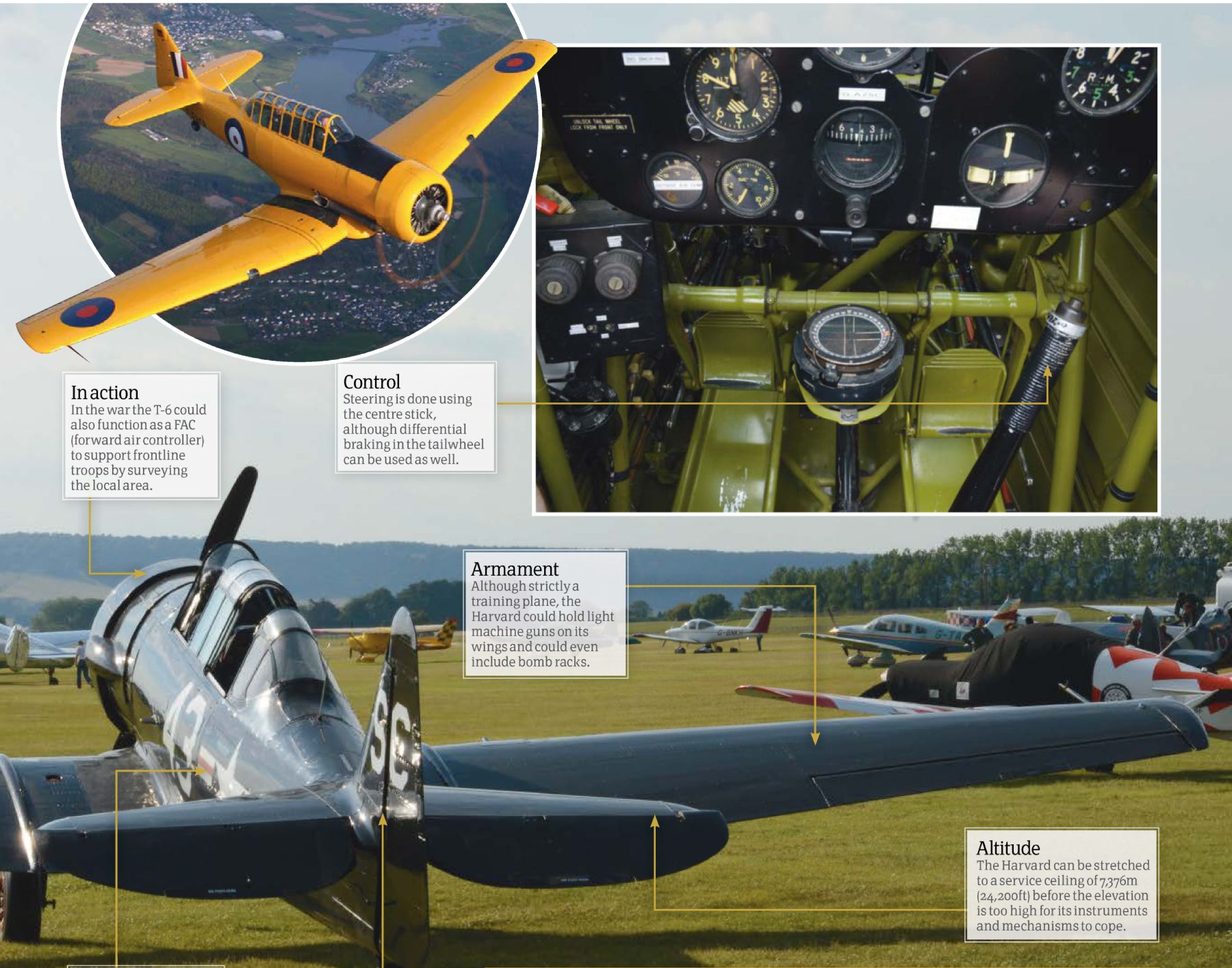
A trip around the T-6 and its main features



Cruising speed
Although the top speed is slightly higher, the Harvard generally cruised at around 230km/h (145mph) at an ideal altitude of 2,440m (8,000ft).

Cockpits
The Harvard contains two cockpits; one for the pilot and one for the learner. Both have very similar instrument panels and the learner solo control can be engaged at any time.

LEFT The front propeller gives it an imposing appearance



In action
In the war the T-6 could also function as a FAC (forward air controller) to support frontline troops by surveying the local area.

Control
Steering is done using the centre stick, although differential braking in the tailwheel can be used as well.

Armament
Although strictly a training plane, the Harvard could hold light machine guns on its wings and could even include bomb racks.

Altitude
The Harvard can be stretched to a service ceiling of 7,376m (24,200ft) before the elevation is too high for its instruments and mechanisms to cope.

Range
On a full tank and in good conditions, the plane can fly up to 1,175km (730mi). That's further than from John o' Groats to Land's End!

Hydraulic system
Activated by a push of a button, the system allows you to use the gears and flaps on the plane.

On the Tiger Moth biplane

A trip on a Tiger Moth is very different to a Harvard flight. As it's a biplane, flights are completed at a much lower altitude and at considerably slower speeds. This is ideal for the beginner pilot to understand the controls before ramping the difficulty up to the Harvard. The controls in the biplane are less responsive than most, so piloting it is actually pretty tricky. The RAF liked this quality as it quickly separated the talented pilots from the rest. The 'Moth' is a semi-aerobatic plane, so it can still loop and barrel roll, which made it an ideal starter plane for RAF training.

The Tiger Moth served as a preliminary training plane

© Eric Dumigan www.airic.ca/Harvards; Corbis

What went wrong at Chernobyl?

Learn how a runaway reaction led to a nuclear disaster…

On 25 April 1986, engineers at the nuclear plant at Chernobyl began a test that would lead to the worst nuclear disaster in history. The power plant, located some 130 kilometres (80 miles) north of Kiev, Ukraine, was completed in 1983. Three years later, engineers ran an experiment to see how long the turbines could continue producing energy in the event of a power cut.

The first fatal error made by the technicians that day was to turn off the safety systems. They would have affected the experiment, which involved running the plant at low power, but this action prevented workers realising the dire situation they were soon to put themselves in.

The process of creating nuclear fission is regulated by control rods, which, when inserted into the reactor core, absorb neutrons and slow production. The idea was to lower lots of these rods to reduce the power output and see what happened. Unfortunately, too many were lowered and the output dropped at too high a rate. Rods were then raised again to increase output, returning to about 12 per cent.

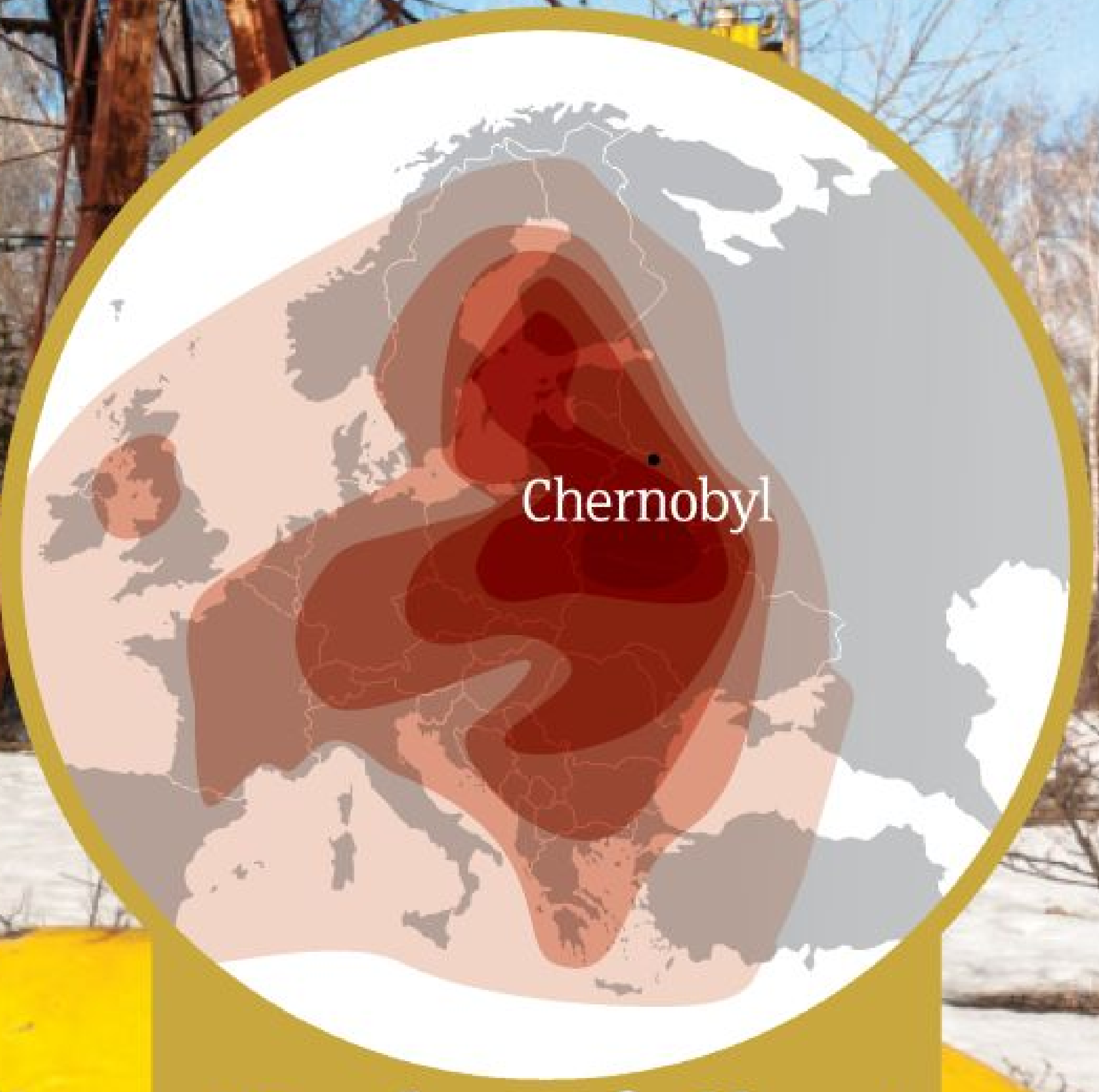
However, due to the rods being raised too far and too quickly, a dangerous power surge occurred and the reactor overheated, the water cooling system unable to cope with the sudden demand, turned to steam.

The emergency button was pressed and the rods began to lower but this led to even more rapid reactions in the core.

In the early hours of 26 April, the reactor's roof was blown off and radioactive material began to escape into the atmosphere.

The fire took nine days to extinguish and the radioactive material had far-reaching health and political consequences.

The site around Chernobyl is still quarantined today



Nuclear fallout

The explosion and meltdown was shocking enough, but worse was still to come in the form of radiation spread and health issues for much of Europe.

31 people died immediately after the event with 28 of those deaths a direct result of radiation poisoning inside and around the power plant.

The worst of the fallout centred around Chernobyl, but increased levels of radiation were detected in areas as far away as the UK, Portugal and Sweden.

Thyroid cancer, caused by the inhalation of contaminated air, has increased tenfold in adolescents in Belarus since 1986 with cases in adults also rising. Cases in children up to the age of 14 also increased, but that number has since reduced due to many of that age group being born after the event.

The impact of the contaminated air has also affected animals, crops and water supplies and the effects are still widely felt to this day. Radiation levels around Chernobyl will remain far higher than average for many millennia.

Countdown to disaster

Find out how history's worst nuclear accident played out

① Safety switches
The safety switches were intentionally turned off to allow the experiment to run without intervention.

② Rods dropped
Control rods were lowered to reduce power output, but the power reduced too much too quickly.

③ Rods raised
In order to get the plant working again, the rods were raised causing a rapid increase in production.

④ Water heating
The all-important cooling water began to overheat, turning to steam and failing to cool the reactor.

⑤ Emergency
Pressing the emergency button lowered the rods again, but they displaced the remaining water.

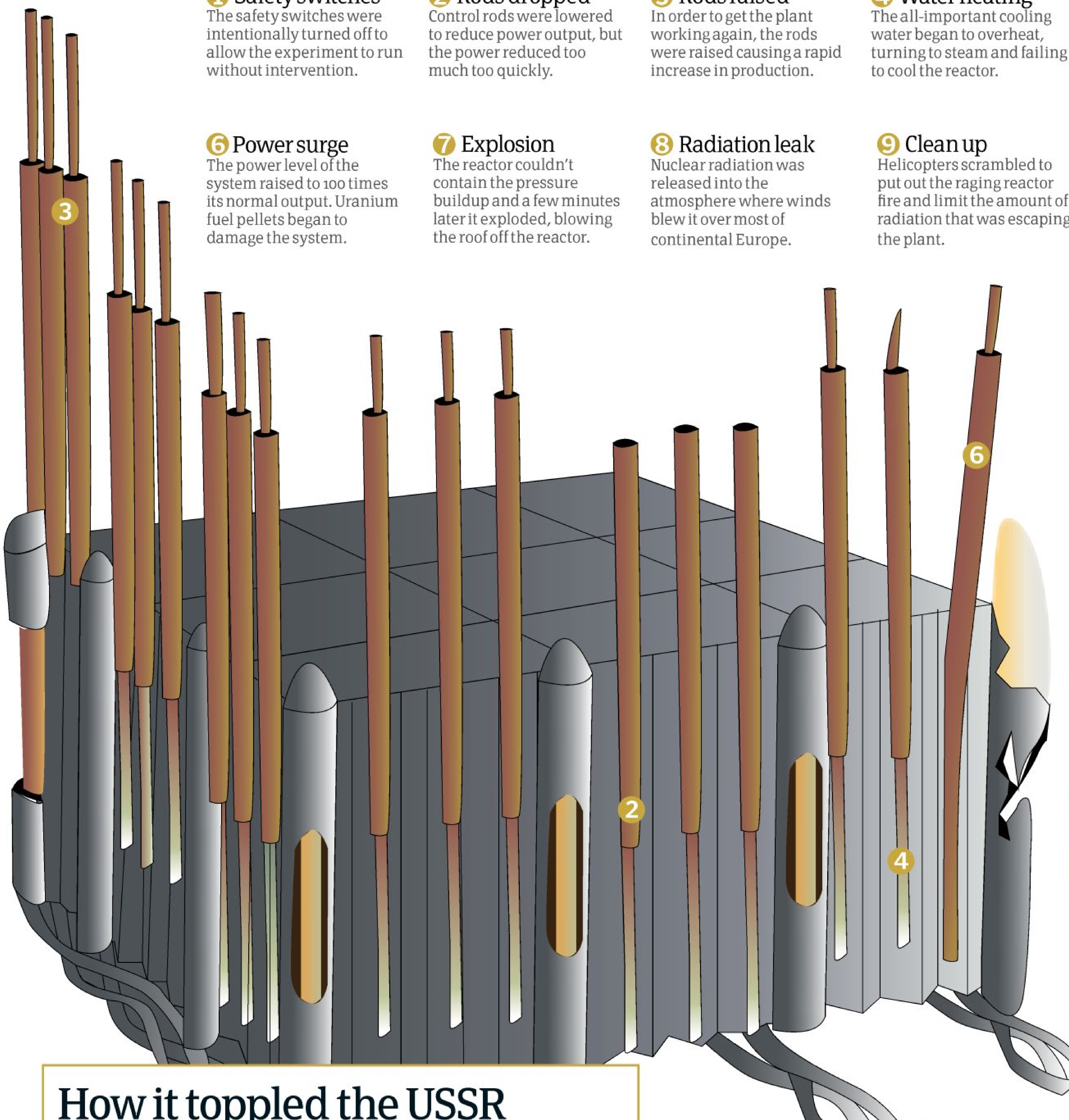
⑥ Power surge
The power level of the system raised to 100 times its normal output. Uranium fuel pellets began to damage the system.

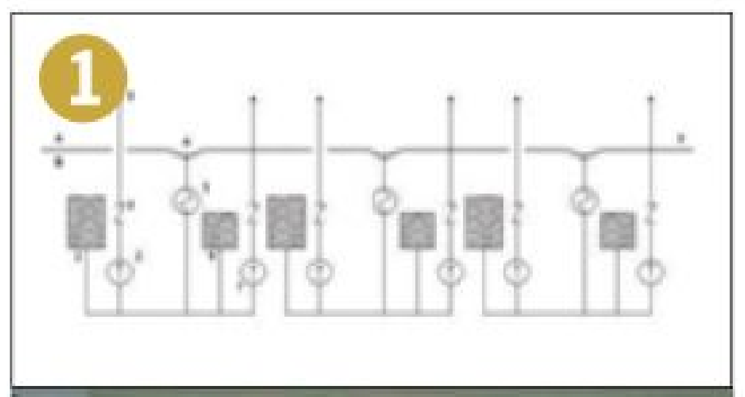
⑦ Explosion
The reactor couldn't contain the pressure buildup and a few minutes later it exploded, blowing the roof off the reactor.

⑧ Radiation leak
Nuclear radiation was released into the atmosphere where winds blew it over most of continental Europe.

⑨ Clean up
Helicopters scrambled to put out the raging reactor fire and limit the amount of radiation that was escaping the plant.

⑩ Sarcophagus
A concrete shell was hastily constructed and placed over the nuclear plant to limit the release of radiation from Chernobyl.





How it toppled the USSR

The leader of the Soviet Union at the time of the Chernobyl disaster, Mikhail Gorbachev, has claimed that the incident was a key factor in the demise of the USSR.

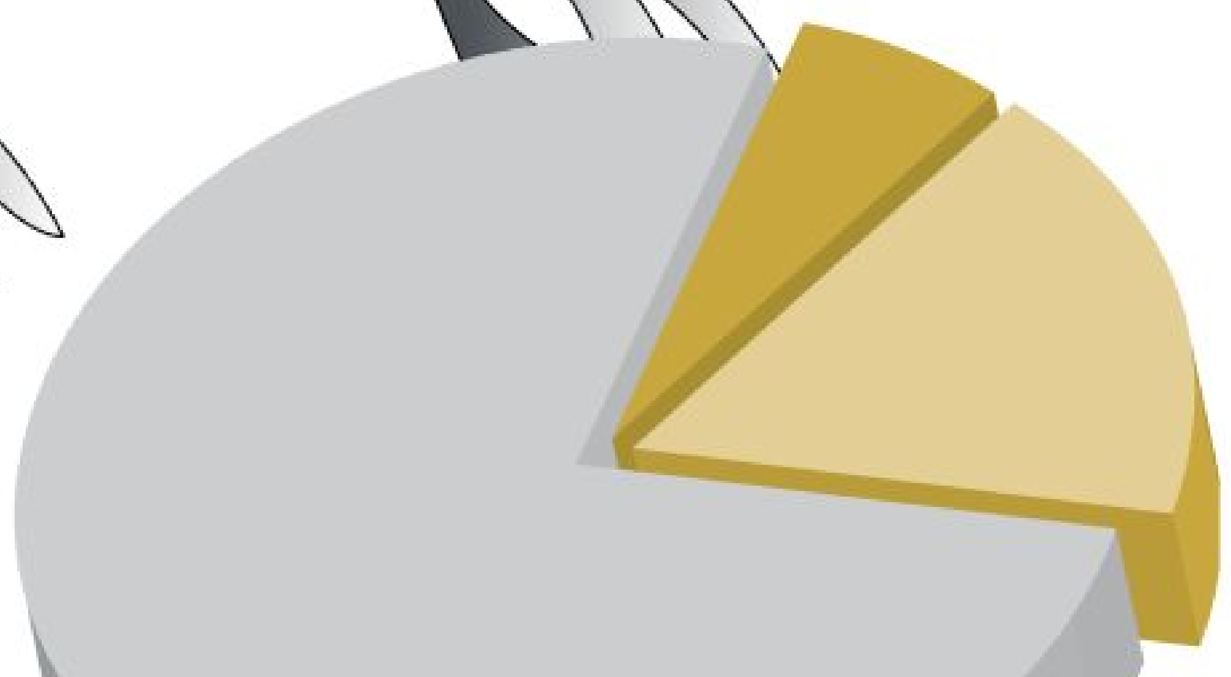
The government's response to the disaster was to try and cover it up as much as possible, with barely any official announcement of it and no warning to residents in the surrounding area as to the dangers of radioactive poisoning. It took a radioactive cloud that passed over Sweden to bring the event to the world's attention.

Furious at the lack of information and protection they had received, especially as Gorbachev had promised a new era of political clarity and honesty, citizens railed against the political system.

The general public lost faith in the government and the government in turn lost control of the general public. Five years later, the Soviet Union was dissolved with Gorbachev quoted as saying, "The nuclear meltdown at Chernobyl [...] was perhaps the real cause of the collapse of the Soviet Union."

Impact of the meltdown

How many were directly affected by the disaster?



▨	**55,000** 6.4% died from radiation
▨	**150,000** 17.4% were left disabled
▨	**655,000** 76.2% underwent medical supervision

© Corbis; Thinkstock

How did Aztec warriors do battle?

Ready yourself for battle as you learn about the martial side of this Central American civilisation

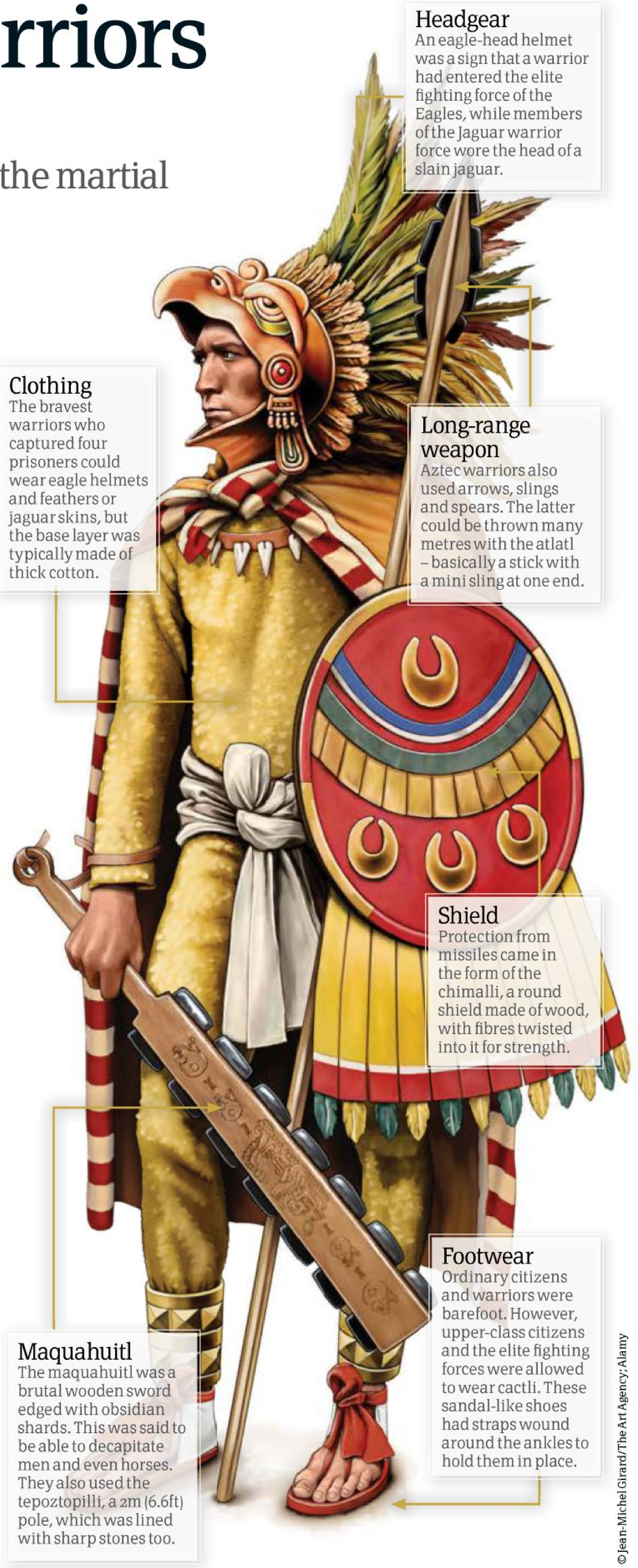
The Aztecs were a fierce and powerful group of warriors, defined by their religious fervour and class system.

New warriors had to work their way up from the bottom by capturing prisoners. This was an important part of a young warrior's introduction into the martial society, as the Aztecs would sacrifice prisoners to the god Huitzilopochtli. Once a warrior had captured a prisoner, he would attain the rank of a warrior.

Most Aztecs wore padded cotton armour called ichcahuipilli, which remained cool in the intense heat of Mexico but was also tough enough to deflect most arrows and darts. However, the elite fighting forces – called the 'Eagles' and 'Jaguars' – dressed as their namesakes. Eagle warriors donned feathers and an eagle-head helmet (see annotated warrior), while Jaguar fighters were wrapped in the skin of the South American big cat. The higher up the social rank you rose, the more elaborate the costume became.

Their main weapon was the maquahuitl, a wooden sword with vicious shards of obsidian embedded down the sides. This deadly tool was capable of beheading a human. The Aztecs were also proficient users of arrows, slings and the atlatl, a throwing device that allowed them to hurl spears harder and faster than possible with the arm alone.

Although fearsome warriors, Aztec armour and weapons could not compete with Spanish steel


Headgear
An eagle-head helmet was a sign that a warrior had entered the elite fighting force of the Eagles, while members of the Jaguar warrior force wore the head of a slain jaguar.

Clothing
The bravest warriors who captured four prisoners could wear eagle helmets and feathers or jaguar skins, but the base layer was typically made of thick cotton.

Long-range weapon
Aztec warriors also used arrows, slings and spears. The latter could be thrown many metres with the atlatl – basically a stick with a mini sling at one end.

Shield
Protection from missiles came in the form of the chimalli, a round shield made of wood, with fibres twisted into it for strength.

Footwear
Ordinary citizens and warriors were barefoot. However, upper-class citizens and the elite fighting forces were allowed to wear cactli. These sandal-like shoes had straps wound around the ankles to hold them in place.

Maquahuitl
The maquahuitl was a brutal wooden sword edged with obsidian shards. This was said to be able to decapitate men and even horses. They also used the tepoztopilli, a 2m (6.6ft) pole, which was lined with sharp stones too.

© Jean-Michel Girard/The Art Agency; Alamy

What was the role of court jesters?

Fooling around with the funniest guys of the medieval world

Back in the days when the kings and queens of Britain had to rule a warring and volatile empire, laughter was in short supply. Therefore, the role of a court jester was massively important for making a monarch smile and ensuring a load of people didn't get their heads chopped off by a grumpy ruler.

Dressed in bright, gaudy colours, wearing a ridiculous hat and often holding a sceptre, the jester would perform at the monarch's request, dancing, singing, telling jokes and doing impressions. He would also be made to perform at meal times because it was believed that cheerfulness aided digestion.

Jesters held a huge position of importance and privilege in the house of a monarch, being able to mock figures of authority in a way that would have resulted in severe punishment for anyone else.

The role of court jester was one of the few that allowed for social mobility in the Middle Ages. Usually, peasants would stay peasants for life, but a court jester would usually be from the lower classes, as they

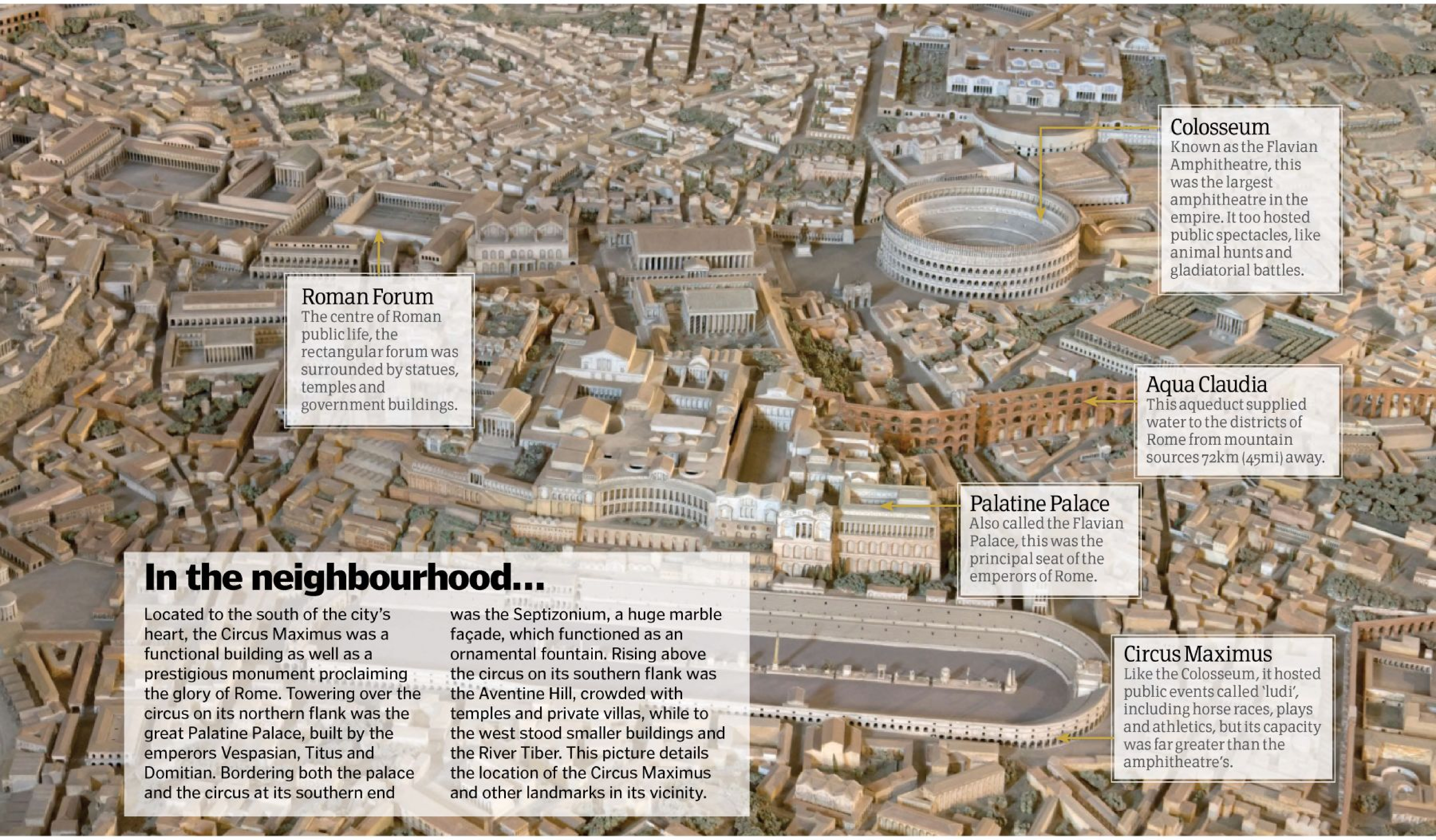
Court jesters were allowed to poke fun at the royalty, something punishable by death if someone else did it

Rib-ticklers and riddles from the past

Q: What's black when you get it, red when you use it and white when you throw it away?
A: Charcoal

Q: Say my name and I disappear. What am I?
A: Silence

Q: My life can be measured in hours. I serve by being devoured. Thin I am quick. Fat I am slow.



Colosseum
Known as the Flavian Amphitheatre, this was the largest amphitheatre in the empire. It too hosted public spectacles, like animal hunts and gladiatorial battles.

Roman Forum
The centre of Roman public life, the rectangular forum was surrounded by statues, temples and government buildings.

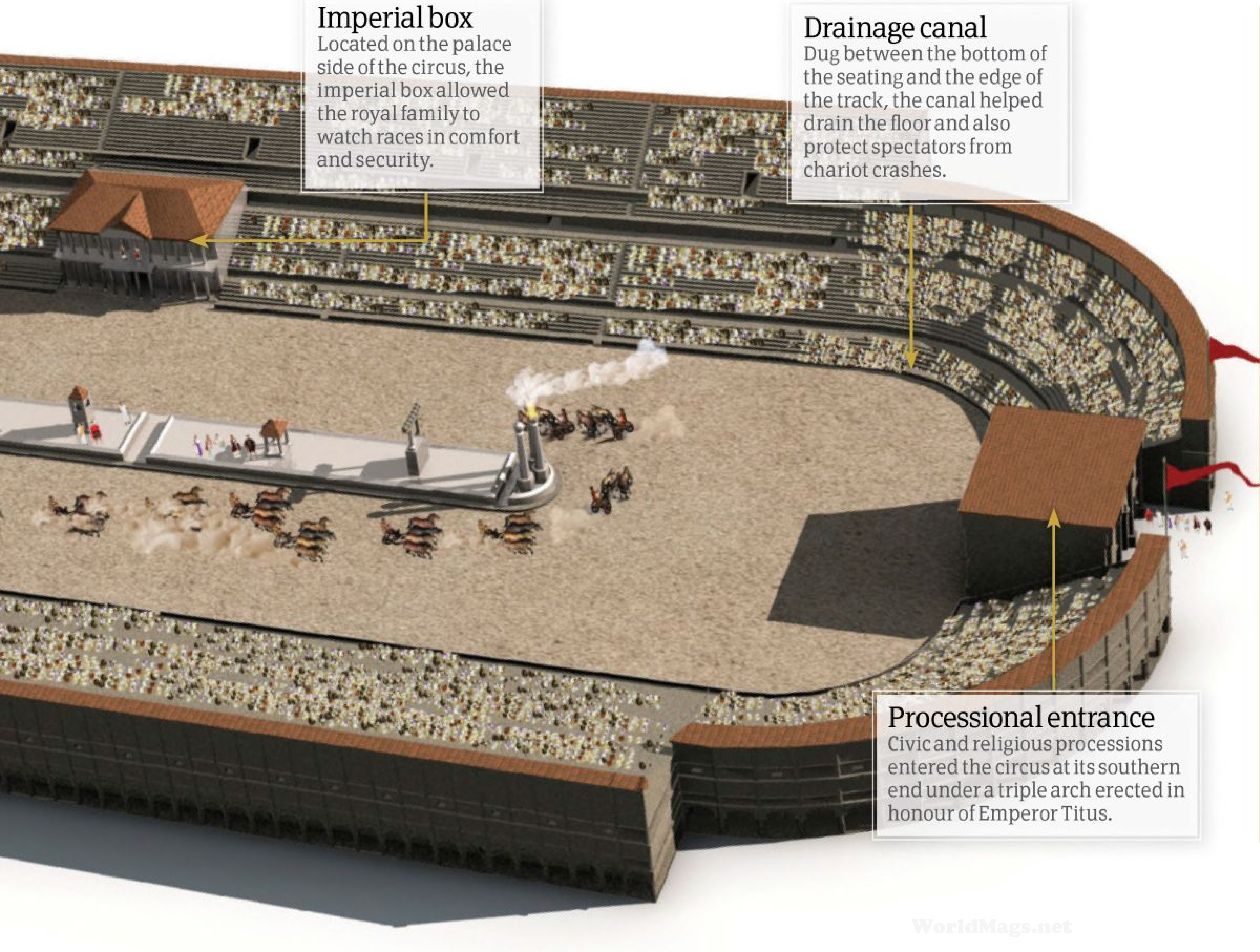
Aqua Claudia
This aqueduct supplied water to the districts of Rome from mountain sources 72km (45mi) away.

Palatine Palace
Also called the Flavian Palace, this was the principal seat of the emperors of Rome.

Circus Maximus
Like the Colosseum, it hosted public events called 'ludi', including horse races, plays and athletics, but its capacity was far greater than the amphitheatre's.

In the neighbourhood…

Located to the south of the city's heart, the Circus Maximus was a functional building as well as a prestigious monument proclaiming the glory of Rome. Towering over the circus on its northern flank was the great Palatine Palace, built by the emperors Vespasian, Titus and Domitian. Bordering both the palace and the circus at its southern end was the Septizonium, a huge marble façade, which functioned as an ornamental fountain. Rising above the circus on its southern flank was the Aventine Hill, crowded with temples and private villas, while to the west stood smaller buildings and the River Tiber. This picture details the location of the Circus Maximus and other landmarks in its vicinity.



Imperial box
Located on the palace side of the circus, the imperial box allowed the royal family to watch races in comfort and security.

Drainage canal
Dug between the bottom of the seating and the edge of the track, the canal helped drain the floor and also protect spectators from chariot crashes.

Processional entrance
Civic and religious processions entered the circus at its southern end under a triple arch erected in honour of Emperor Titus.

Chariot racing in Roman times

Chariot racing was probably the Roman world's equivalent of football. Inherited from the Ancient Greeks and Etruscans, the sport was refined by the Romans and practised throughout the empire. Dangerous to horses and charioteers alike, there were frequent accidents and even deaths.

There could be as many as 24 chariot races in a circus per day and although there were basic rules for behaviour while racing, charioteers often deliberately crashed into opponents or tried to force them into the central barrier.

An average race in the Circus Maximus would see up to 12 teams of charioteers lined up against each other, each chariot drawn by four horses competing over a distance of 6.4 kilometres (four miles). There were four principal teams – the Reds, Whites, Greens and Blues – the latter two of which rose to great prominence.

Fans followed their team's progress closely, much like football clubs do today. Fierce rivalry often resulted in violence between factions.

A highly paid sport, the most famous Roman charioteer, named Gaius Appuleius Diocles, won 1,462 out of his 4,257 races. When he retired at the age of 42, he had amassed winnings of 35,863,120 sesterces – approximately £9 billion ($15 billion) in today's money – making him the highest-paid sports star in history.

© SPL; Alamy

How did Leonardo da Vinci try to fly?

Discover the secrets behind the legendary inventor's incredible flying machine

Few individuals truly fit the much-overused sobriquet of 'man ahead of his time', but Leonardo da Vinci is one of the select band who undoubtedly fits into this category. His mind seemed to be of another time entirely, devising all sorts of inventions that would either pre-empt or form the basis for modern-day equivalents. The item that perhaps best of all encapsulates his capacity to work beyond the constraints of his time, however, is his visionary ornithopter flying machine.

Having spent much time watching and studying the flight of birds, he observed the different ways they flapped their wings while taking off and in mid-flight, and sought to mimic them in the construction of his ornithopter. Sharing similarities with the paragliders of today, it required a solo pilot to manually operate a system of pullies, levers and pedals with his hands and feet in order to simulate flight. A hand crank increased the production of energy and the wings were designed to flap – much like those of a bird.

However, while it looked impressive on the page, da Vinci's ornithopter was never physically realised in his day. While it may well have worked while in flight, the task of actually taking off proved to be an insurmountable obstacle, as there wasn't a known way of producing enough power to actually get it off the ground. ⚙

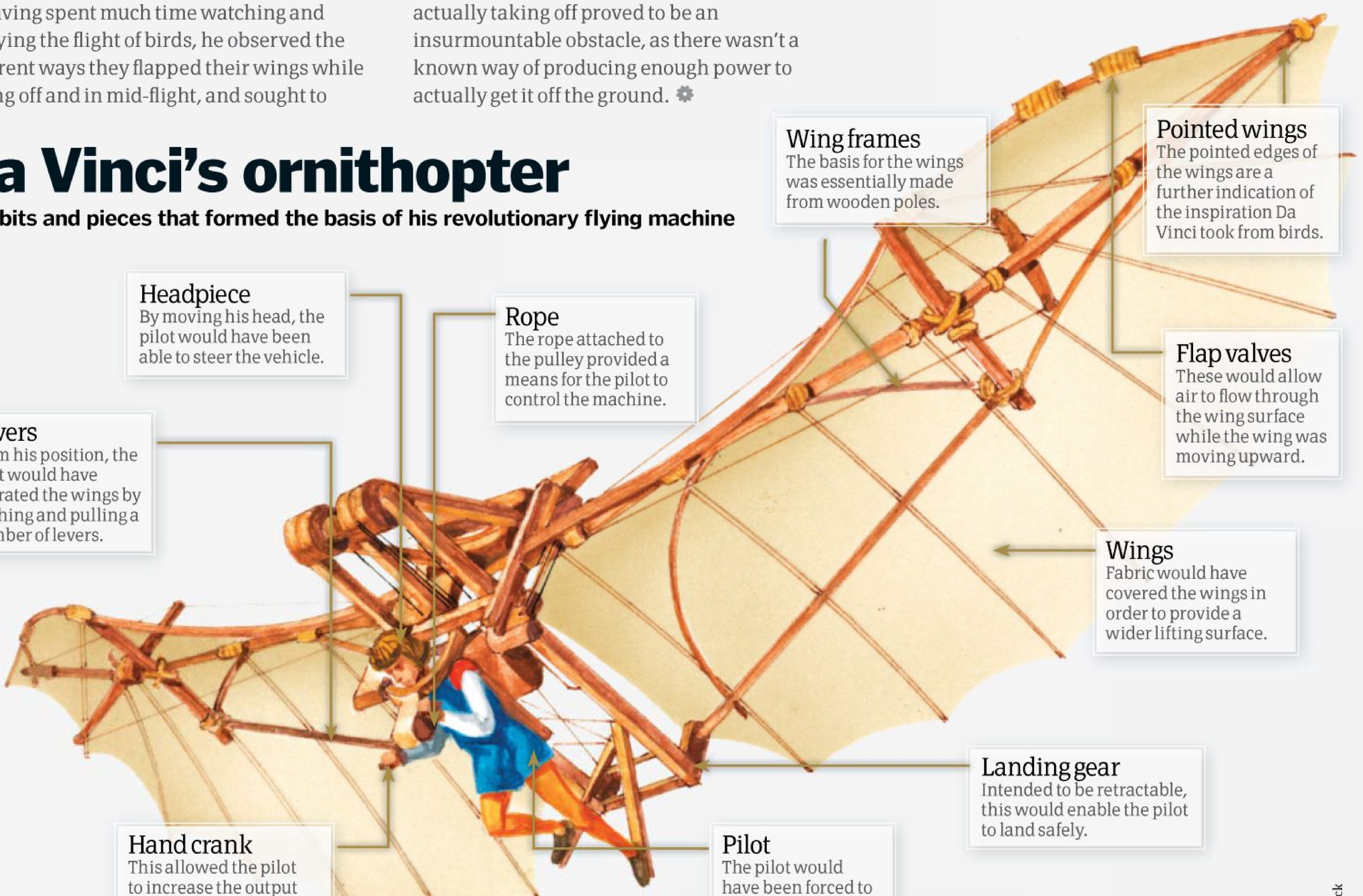
Da Vinci's other flying machines

Da Vinci didn't limit his pursuit of flight to just his ornithopter. Predating its invention by over 400 years, one of his designs reveals something akin to a modern-day helicopter. Also known as an aerial screw, its blades revolved like a corkscrew, compressing air in order to gain flight – a principle shared by its eventual successors. Although the theory was sound, modern-day scientists believe that it would have been too heavy to achieve flight, and as such remained strictly in the drawing book.

He is also credited with devising early designs for what would become what we know as the parachute. Despite its triangular shape and wooden frame causing many to doubt its effectiveness, it a prototype based on the same design was constructed and tested in 2000 – where it was proven to work perfectly.

Da Vinci's ornithopter

The bits and pieces that formed the basis of his revolutionary flying machine



Wing frames
The basis for the wings was essentially made from wooden poles.

Pointed wings
The pointed edges of the wings are a further indication of the inspiration Da Vinci took from birds.

Headpiece
By moving his head, the pilot would have been able to steer the vehicle.

Rope
The rope attached to the pulley provided a means for the pilot to control the machine.

Flap valves
These would allow air to flow through the wing surface while the wing was moving upward.

Levers
From his position, the pilot would have operated the wings by pushing and pulling a number of levers.

Wings
Fabric would have covered the wings in order to provide a wider lifting surface.

Landing gear
Intended to be retractable, this would enable the pilot to land safely.

Hand crank
This allowed the pilot to increase the output of energy from the flying machine.

Pilot
The pilot would have been forced to lie still where he was positioned.

© Thinkstock

What did an Apothecary do?

What are the origins of the pharmaceutical industry?

It's thought the first apothecary emerged in Ancient Babylon and was introduced to the West by Galen, a Roman doctor. It originally revolved around the preservation of food, but its focus shifted to the relationship of drugs and medicines with living systems and the process of recording symptoms for the cure and prevention of disease.

The preparation and selling of medicines was handled by an apothecary after the Society of Apothecaries was established in London in 1617. By the 19th century, their role had evolved. The Apothecaries Act in 1815 meant that chemists now had to have formal qualifications and provide medical care and surgery, while new chemist shops would look after the retail side. The practice evolved into pharmacology as new substances were developed such as morphine, strychnine and quinine. Morphine was isolated in 1805 by Friedrich Setürner who heated opium in methanol.

Apothecaries remained prominent throughout the 20th century, with about 100 apothecaries still in the USA during the 1960s. The age of apothecaries all but came to an end in the 1980s as large chain drug stores superseded them.

A replica of an 18th-century apothecary shop in Mexico

Apothecary treatments

1 Artificial leech

Rather than using real leeches for bloodletting, a man-made alternative was created by Carl Baunscheidt in the mid-19th century. It was a pen-like device with a group of tiny needles on the end.

2 Vesiculation

Used to combat madness and hypochondria, this involved intentionally raising blisters on the skin.

3 Clysters

A medicine injected to help nutrition and cleanse the bowels. Along with vomiting and bloodletting this was seen as a way of 'purging' the body of bad elements.

4 Chamomile

A flower that had sedating and anti-inflammatory effects, it was prescribed for colds and infections and was one of many plants used in medicine.

How are bells made?

The process of chime creation explained

Originally a basic percussion instrument created in China as early as 3,000 BCE, bells now come in all sorts of shapes and sizes.

They are made in a foundry (a metal casting factory), where the bell's design must be calculated precisely in order to strike the right pitch. First, the bell pattern is cut out in two wooden templates called strickle boards as the basis for the moulds. Two moulds are made: inside (core) and outside (cope). They are made out of clay and sand to make a material known as loam. The loam core and cope are then clamped together to make the mould case and a runner box is used to act as a funnel for liquid metal to be added. The furnace is heated up to 1,150 degrees Celsius, which is above the melting point of the copper and tin used in the bell. Once this process is finished, the metal's impurities or 'slag' have to be removed and the bell can now be cast. The liquid metal is poured into the mould case and takes about two days to cool into place.

All that's left to do now is to skirt (smooth) the edges to ensure the aesthetic design is correct and tune it so the desired sound will be produced. Every bell can produce five chime tones: the octave, the fifth, the minor third, the prime and the hum. They were originally measured by a tuning fork.

The most famous bell foundry is in Whitechapel, London. It was established during the reign of Elizabeth I in 1570, making it Britain's oldest manufacturing company. It constructed the Liberty Bell in 1752 and Big Ben in 1858 and is still in business today.

What is inside a Whippet tank?

The fastest British tank of WWI, the Whippet was a deadly mobile gun nest

The only British medium tank to see action in World War I, the Medium Mark A – later known as the Whippet – was proposed by businessman William Tritton on 3 October 1916 and developed by his chief engineer, William Rigby. Tritton, along with Lieutenant Walter Wilson, was the inventor of the Mark I heavy tank and the Little Willie prototype, and he saw a gap in the battlefield for something faster than the Mark I's less-than-impressive top speed of 5.9 kilometres (3.7 miles) per hour.

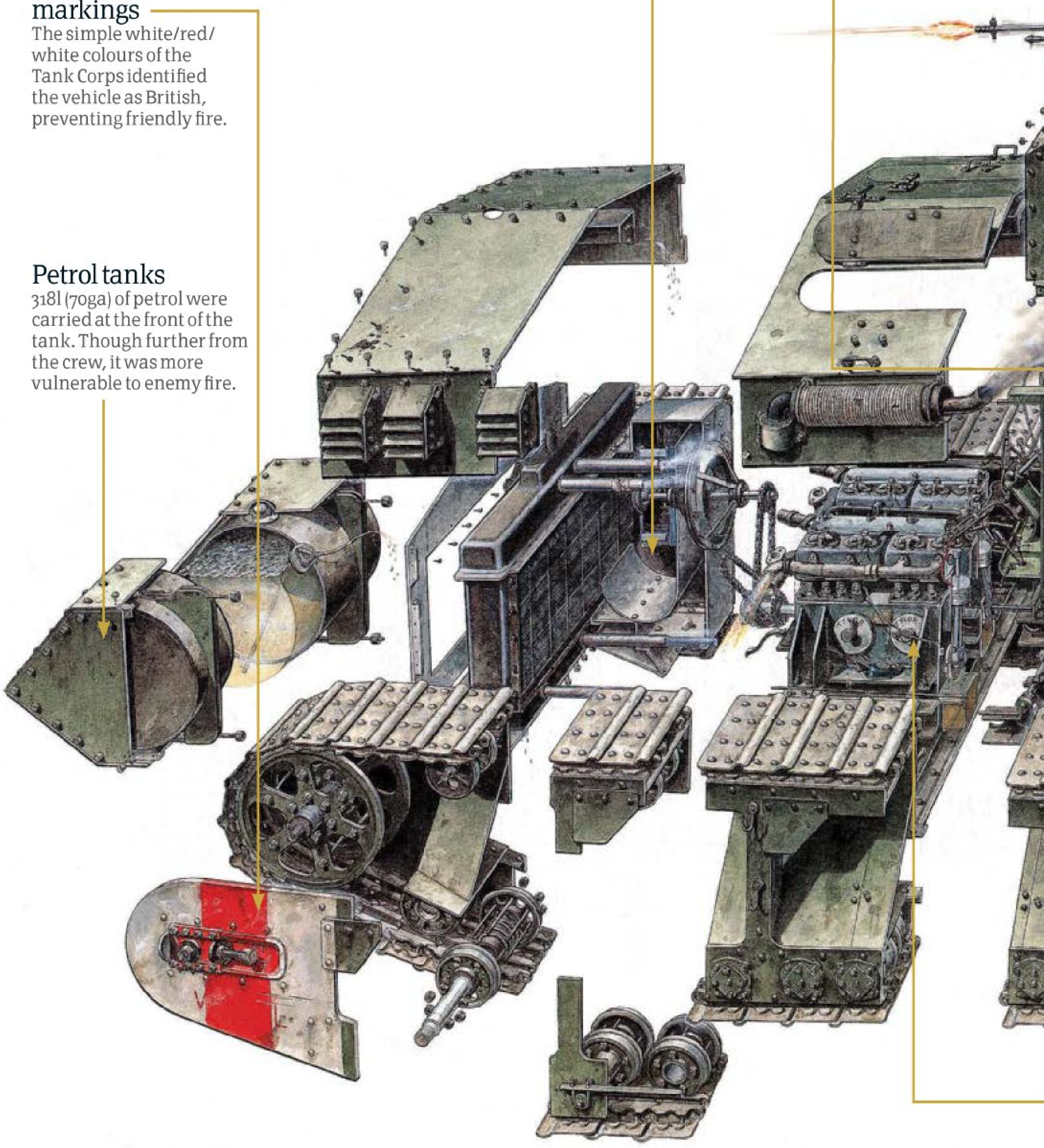
Able to hit 12.9 kilometres (eight miles) per hour the Medium A wasn't the hammer that delivered the battlefield's killing blow like the Mark I, but was designed to be more of a chisel, able to force open the weak points already subject to infantry assault, artillery bombardment or assault from heavier models. While the Mark I's main weapons were two six-pounder naval guns, the Whippet relied on four machine guns mounted on its fixed turret, which proved devastating to infantry caught in the open .

On 24 April 1918 just seven tanks ambushed two German infantry battalions near Cachy in Northern France and killed over 400 men. In another incident that proved just how devastating these fast-moving machine-gun nests could be, a single Medium A – called Musical Box by its crew – advanced so far on 8 August 1918 that it was completely cut off. Musical Box spent nine hours rampaging behind the German lines, destroying an artillery battery, an observation balloon, the camp of an infantry battalion and raiding a column of German infantry before bullets pierced a petrol can, causing fuel to leak and fill the cabin with fumes. Fighting on in their gas masks, a field gun finally disabled the tank. Amazingly, two of the three crewmen actually survived and were taken prisoner.

> "The Whippet relied on four machine guns mounted on its fixed turret, which proved devastating to infantry"

Behind the armour

A look inside WWI's Whippet tank



Cooling system
A fan and radiator, much like one on a car, cooled the engine and vented the heat through slats (or 'louvres') in the armour.

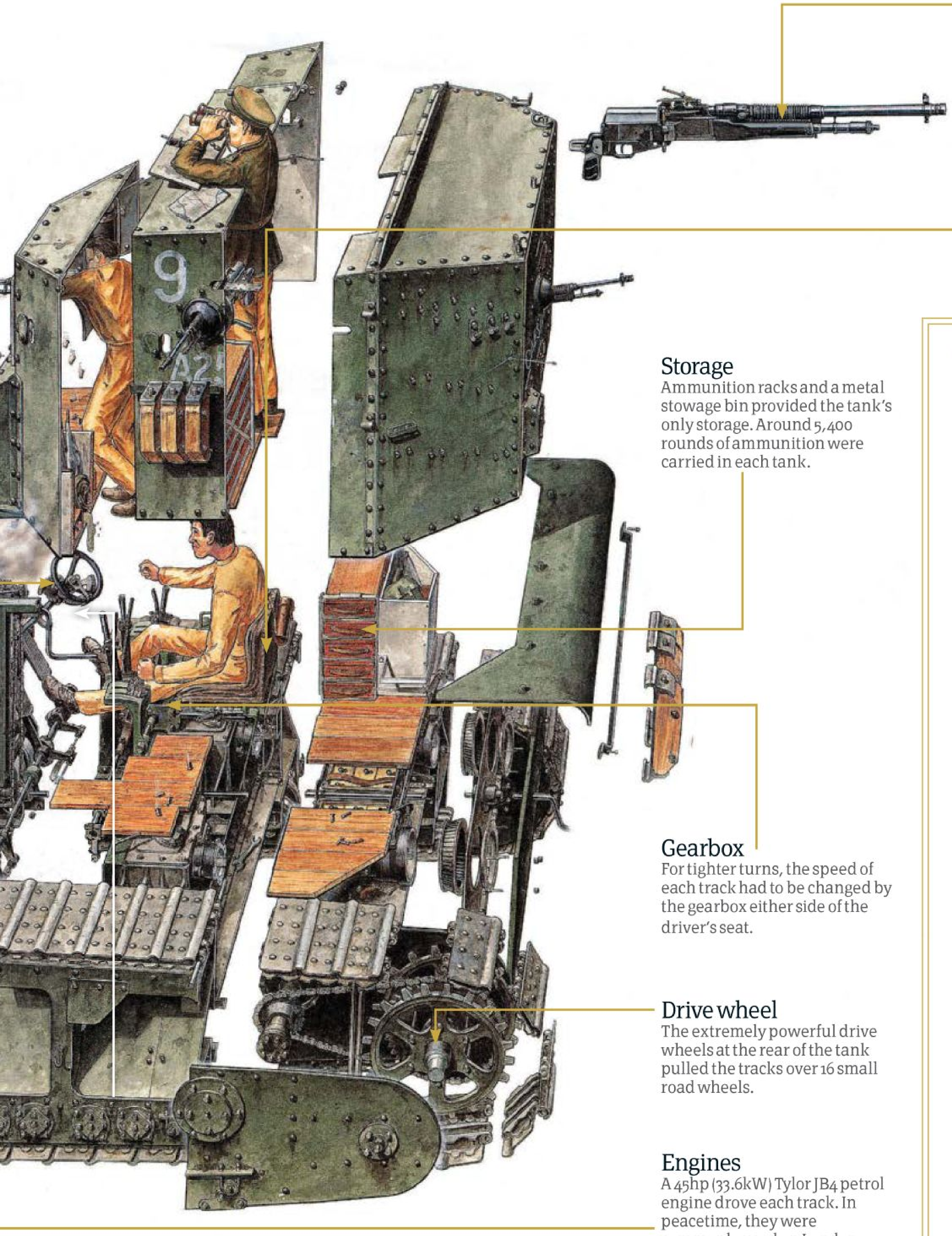
Steering column
The steering column controlled the throttle, speeding up one track and slowing the other automatically so the tank could turn.

Identification markings
The simple white/red/white colours of the Tank Corps identified the vehicle as British, preventing friendly fire.

Petrol tanks
318l (70ga) of petrol were carried at the front of the tank. Though further from the crew, it was more vulnerable to enemy fire.

Son of Whippet

Mark I co-creator Walter G Wilson had been left out of Tritton's Medium A project and thought he could do better. The Medium B's real innovations was the sloped armour at the front of the hull, the ability to lay a smoke screen and having the crew in a separate compartment from the engine – all now standard features in tank design. The first prototype was ready in September 1918, but the end of the war on 11 November 1918 led to the order being cancelled with only 100 tanks in service. Confusingly enough, the Medium B was also called Whippet.



Machine guns
Four Hotchkiss machine guns, firing up to 600 rounds per minute. There was only one gunner so he had to jump between guns.

Driver's seat
Although the Whippet typically had three crewmen, there was only seat for the driver. Everyone else had to crouch quite awkwardly.

Storage
Ammunition racks and a metal stowage bin provided the tank's only storage. Around 5,400 rounds of ammunition were carried in each tank.

Gearbox
For tighter turns, the speed of each track had to be changed by the gearbox either side of the driver's seat.

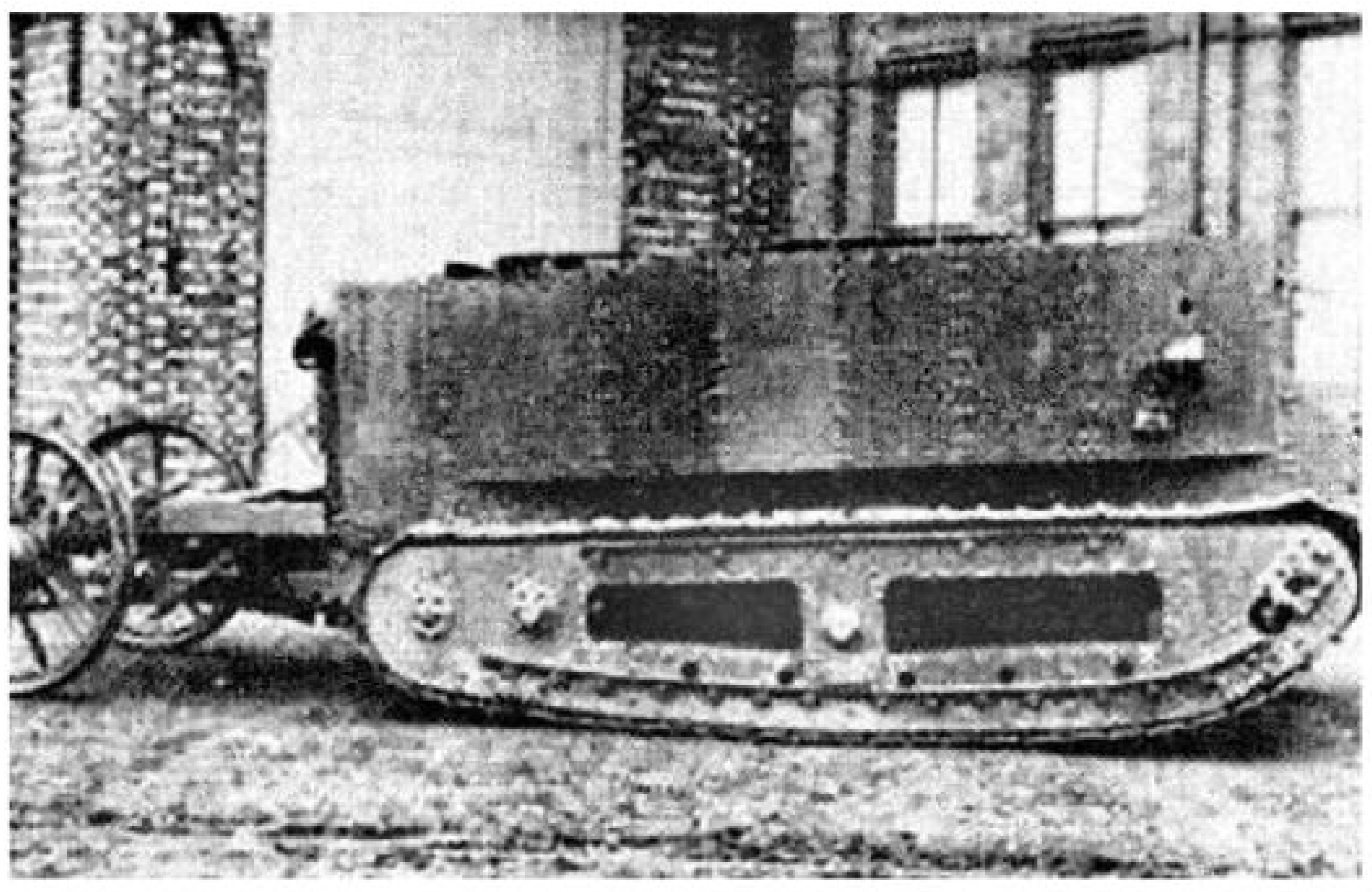
Drive wheel
The extremely powerful drive wheels at the rear of the tank pulled the tracks over 16 small road wheels.

Engines
A 45hp (33.6kW) Tylor JB4 petrol engine drove each track. In peacetime, they were commonly used on London double-decker buses.

The birth of the tank

The tank emerged out of a need for an armoured vehicle that could traverse the muddy terrain of the Western Front of World War I. The army weren't interested, but the First Lord of the Admiralty – future British Prime Minister Winston Churchill – saw potential in the idea and adopted it as a Royal Navy project, forming the Landships Committee in February 1915.

A contract was put out to William Tritton, chairman of William Foster & Co, a company based in Lincoln and best known for producing threshing machines, steam tractors and traction engines, to produce a prototype 'landship' using two caterpillar tracks. Developed in great secrecy, factory workers were told they were constructing mobile water carriers for use in the desert. Because the abbreviation WC also meant toilet, the factory employees started calling it a 'water tank' instead. The word 'tank' stuck, while the word 'landship' quite obviously didn't!

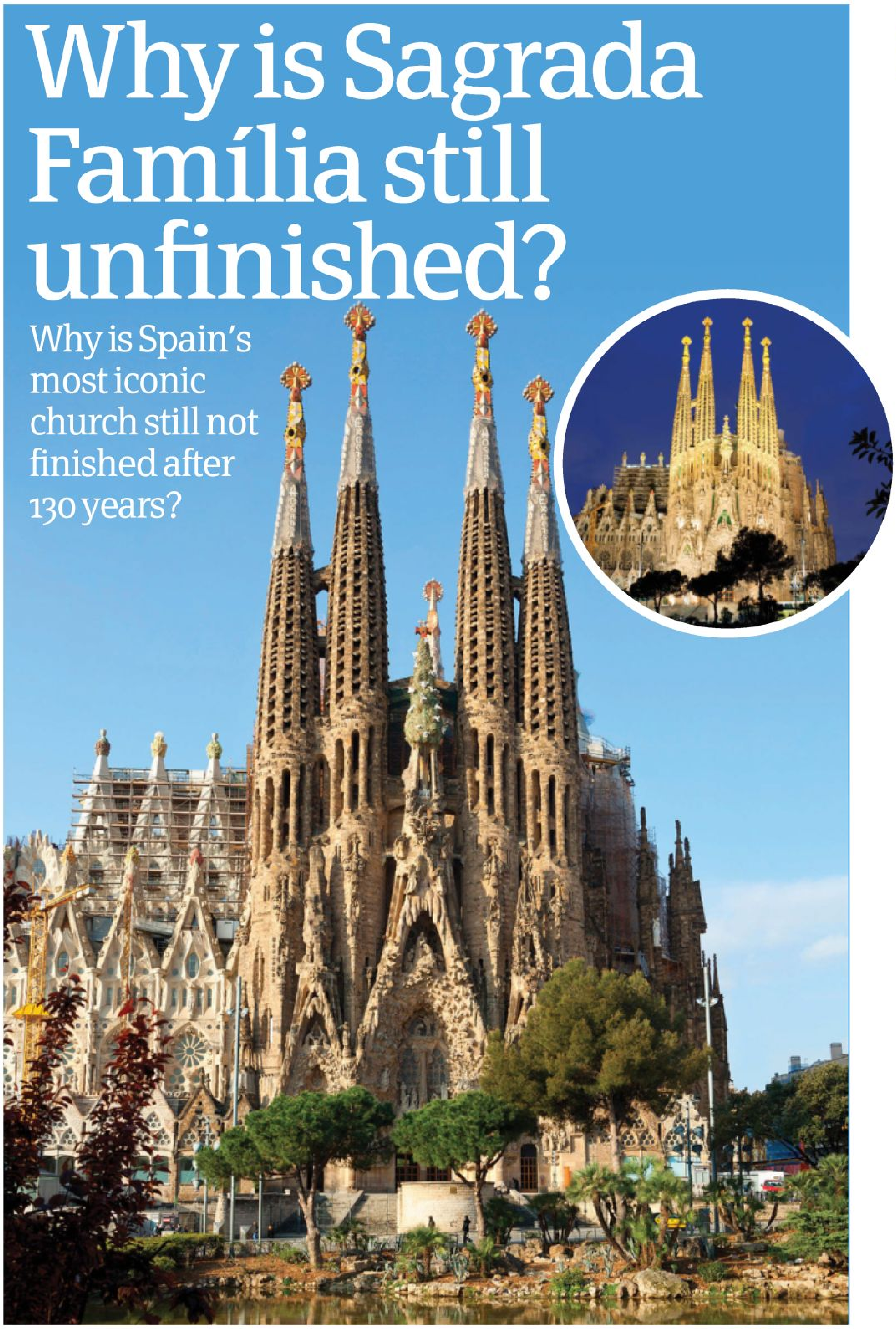


The first prototype, Little Willie

© DK Images

Why is Sagrada Família still unfinished?

Why is Spain's most iconic church still not finished after 130 years?



Sagrada Família is not a cathedral, because it doesn't have a bishop. But it was intended from the outset to be cathedral sized. The design calls for 18 spires, seven side chapels and three grand facades. The raised choir space has room for 1,100 singers and the six separate organs will be playable from a central console to give a single instrument with 8,000 pipes. When it is completed, Sagrada Família will be the tallest church building in the world. But the extraordinary gingerbread architecture has divided opinion from the very beginning. George Orwell called it "one of the most hideous buildings in the world."

The church was commissioned by a pious bookseller called Josep Maria Bocabella and the first stone was laid in 1882. The Spanish architect Antoni Gaudí took charge of the design a year later. Because it has never received money from government or the Catholic Church, the pace of building work has always depended on the money that could be raised privately. During Gaudí's lifetime only the crypt, the apse above it and one of the spires had been completed. Gaudí himself was not concerned with the slow progress and famously said: "My client is not in a hurry." At the time of Gaudí's death at age 73 in 1926, less than a quarter of the Sagrada Família was complete.

Today, Sagrada Família is a UNESCO World Heritage Site and one of the most popular tourist attractions in Spain. The admission charge and other fund raising generates more than a massive €25 million (£20 million), which now allows an extraordinary level of craftsmanship and detail on the construction. But Sagrada Família is not a museum piece. Modern construction techniques and materials are used wherever possible, including reinforced concrete, computer-aided design and 3D-printing of plaster decorations. Even though Gaudí lies buried in the crypt at Sagrada Família, a team of engineers and craftsmen remain dedicated to finishing the work he began.

Construction ahead

The road toward completion of the Sagrada Família has been long and arduous – and there is still some way to go…

1882

Work begins under the architect Francisco de Paula del Villar y Lozano. It is originally designed as a Gothic revival church.

1883

Gaudí takes over after the original architect disagrees with the project promoter and resigns.

1894

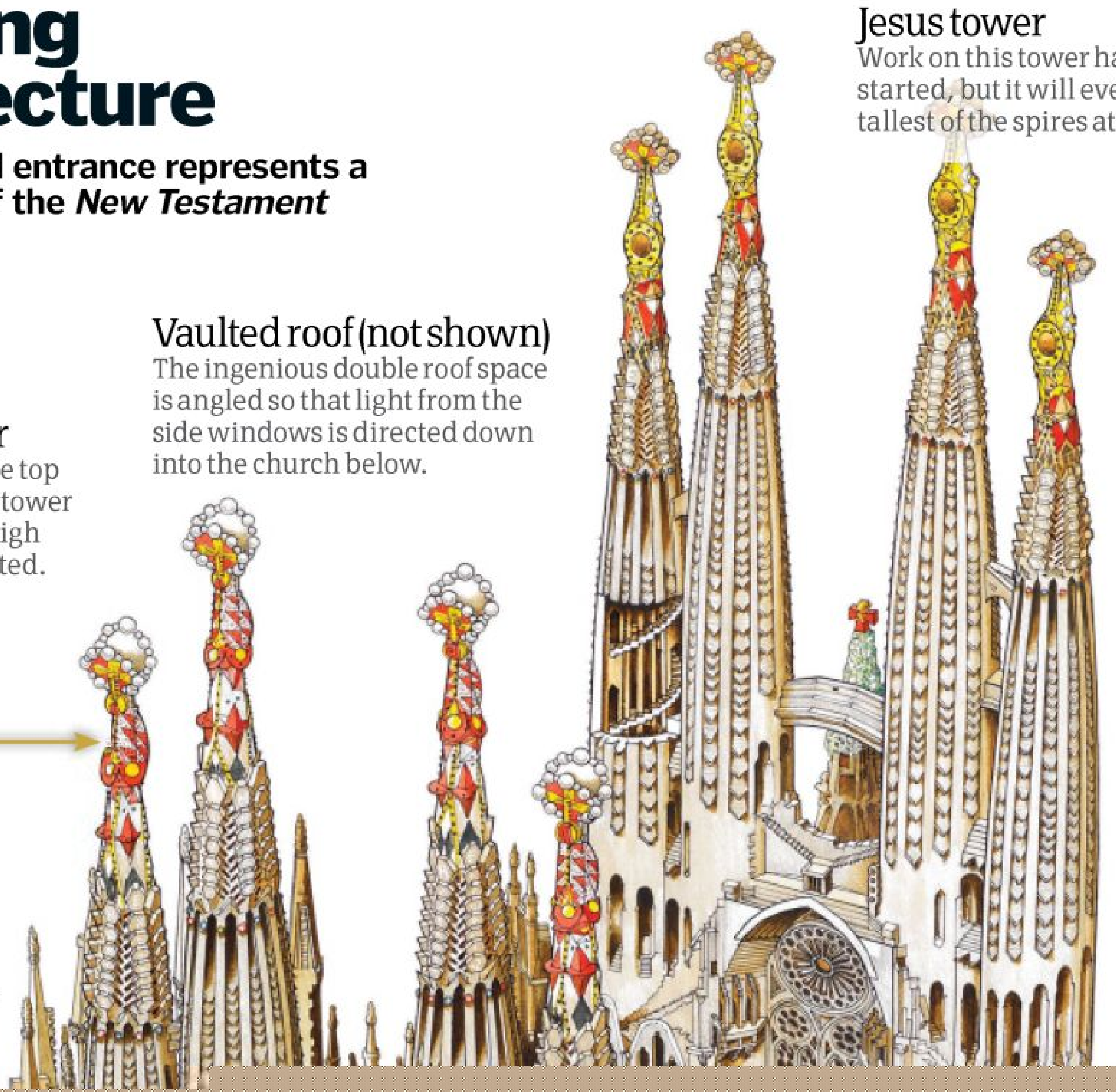
More than a decade later, the crypt and apse (the semi-circular area behind the altar) are the first parts of the church to be finished.

1926

Gaudí dies, aged 74. He has spent over 42 years working on Sagrada Família, but more than 75 per cent of it is still unbuilt.

Inspiring architecture

Every tower and entrance represents a different part of the *New Testament*



Jesus tower

Work on this tower has not even started, but it will eventually be the tallest of the spires at 170m (558ft).

Vaulted roof (not shown)

The ingenious double roof space is angled so that light from the side windows is directed down into the church below.

The Mary tower

Currently missing the top half of the spire, this tower will be 123m (404ft) high when finally completed.

Apostle towers (not shown)

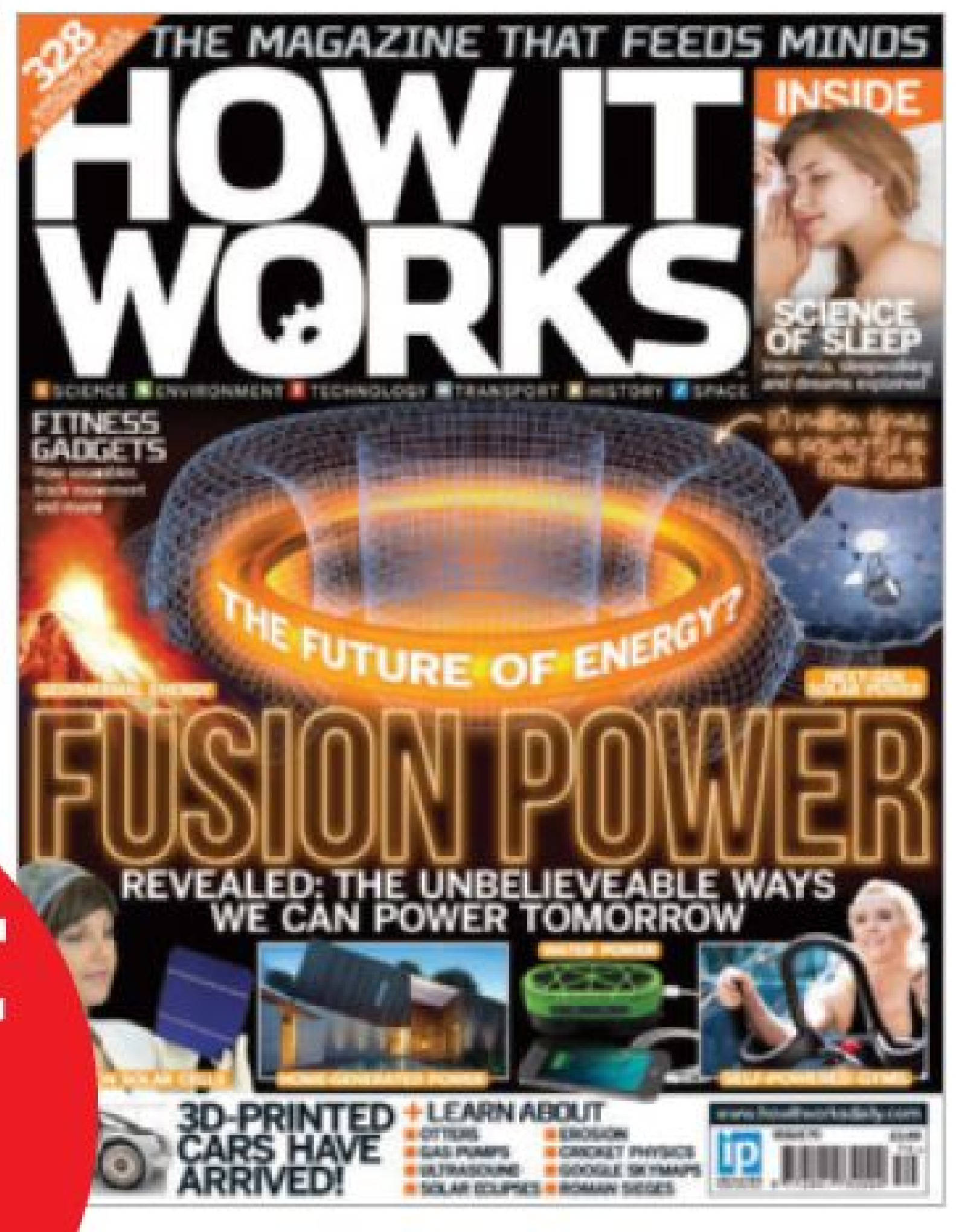
One for each of Jesus' 12 apostles. The four at the south end represent Andrew, Peter, Paul and James the Greater.

Evangelist towers

These will be topped with a statue to represent each of the four canonical gospel writers:

Modern interior

Sagrada Família uses elaborate branching internal columns to direct all the weight of the building downward. This allows it to have a durable stone roof, instead of the traditional wooden design, and avoids the need for flying buttresses (which Gaudí called 'crutches') to prop up the walls on the outside. The shapes of the columns are modelled on twisting plant stems. At their base, each column begins as a polygon or star, and the number of sides or points doubles at intervals as the columns rise, until they all become cylinders at the top. The stained glass windows are another deliberate departure from traditional Catholic church



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